Máster Internacional en
GESTIÓN PESQUERA SOSTENIBLE
(6ª edición: 2015-2017)

TESIS

presentada y públicamente defendida
para la obtención del título de

MASTER OF SCIENCE

Trends on the state of Mediterranean fish stocks

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Septiembre 2017

Universitat d'Alacant
Universidad de Alicante

GOBIERNO DE ESPAÑA
MINISTERIO DE AGRICULTURA Y PESCA, ALIMENTACIÓN Y MEDIO AMBIENTE

CIHEAM
Instituto Agronómico Mediterráneo de Zaragoza

MASTER EN GESTIÓN PESQUERA SOSTENIBLE
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TRENDS ON THE STATE OF MEDITERRANEAN FISH STOCKS

Kafaf Ouafae

TESIS PRESENTADA Y PUBLICAMENTE DEFENDIDA PARA LA OBTENCION DEL TITULO DE MASTER OF SCIENCE EN GESTIÓN PESQUERA SOSTENIBLE

Alicante

29 Septiembre de 2017

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Ouafae, KAFAF

Trabajo realizado en la Comisión General de Pesca del Mediterráneo, Roma, Italia, bajo la dirección del Mr. Miguel Bernal.

Presentado como requisito parcial para la obtención del Diploma Master of Science en Gestión Pesquera sostenible otorgado por la Universidad de Alicante a través de Facultad de Ciencias y el Centro Internacional de Altos Estudios Agronómicos Mediterráneos (CIHEAM) a través del Instituto Agronómico Mediterráneo de Zaragoza (IAMZ).

Esta Tesis fue defendida el día 29 de septiembre de 2017 ante un Tribunal Formado por:

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The present Master Thesis will be the basis of a chapter on the same subject that is expected to be included in the 2018 biennial flagship publication “The State of Mediterranean and Black Sea Fisheries (SoMFi)” of the General Fisheries Commission for the Mediterranean (GFCM) at http://www.fao.org/gfcm/en. The conclusions and recommendations presented in this Master thesis have not been endorsed by the GFCM, and may therefore be subsequently modified.

ACKNOWLEDGEMENTS

First of all, I would warmly thank my god to guide me choosing an amazing field, to help me during each second spent in working on this master thesis and to give me perseverance and good health allowing me to overcome all obstacles.

Many thanks to CIHEAM, IAMZ, UA and all their staffs for organizing this international master, which has a good reputation both globally and scientifically and for the high-level training, guidance and assistance they provide.

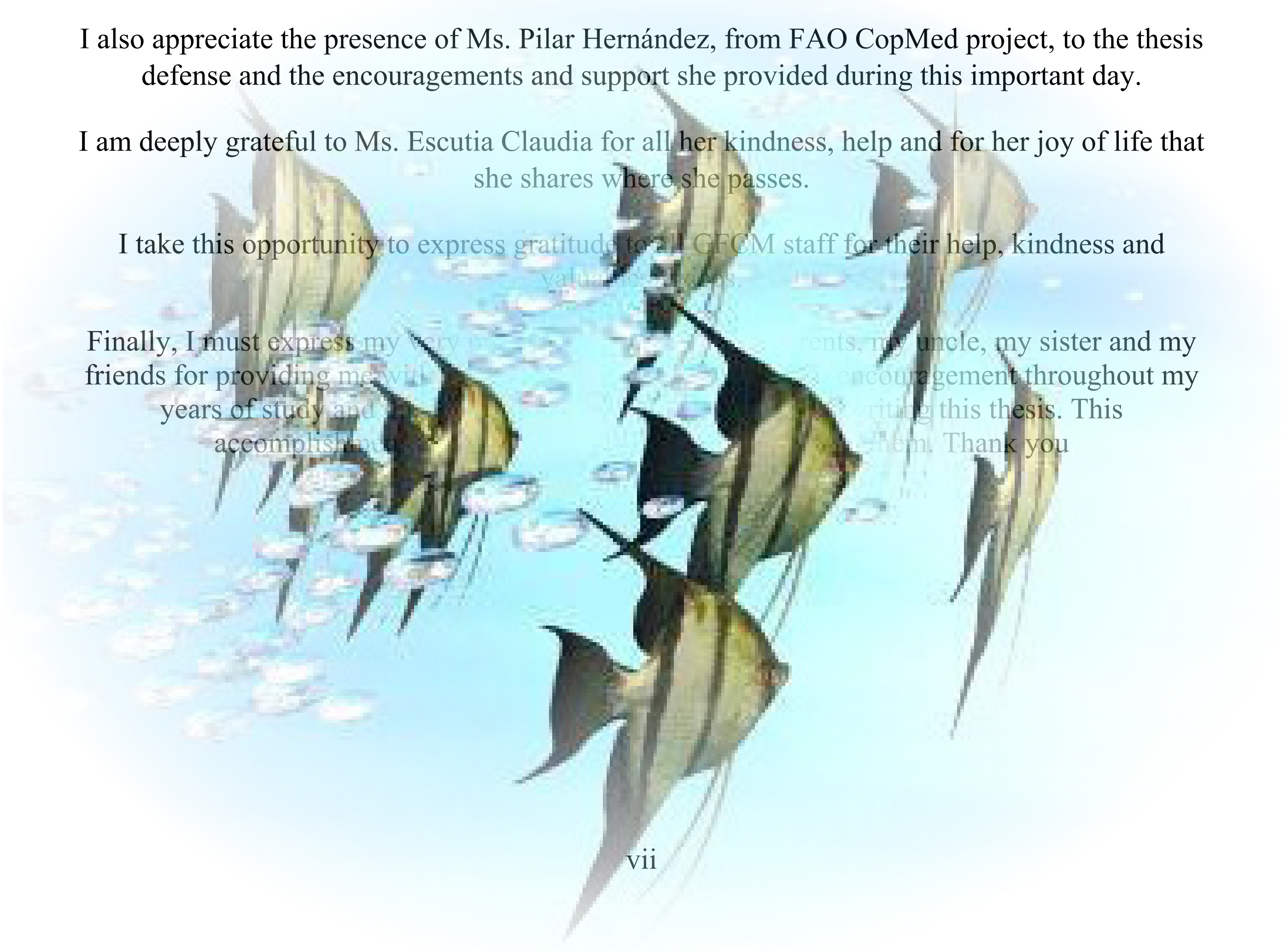
A specific thanks and gratitude to the director of the master, the Professor Jose Luis Sanchez and to Dr. Bernardo Busorco from IAMZ for all the helps, encouragements and valuable advices they gave me throughout this master.

I wish to express my sincere thanks to Mr. Abdellah Srour, General Secretary of GFCM, for this great opportunity and for all their encouragements, kindness and advices.

I owe my deepest gratitude to my thesis supervisor Mr. Miguel Bernal, Fishery Resources Officer at GFCM. The door to Mr. Bernal office was always open whenever I ran into a trouble spot or had a question about my research or writing. He consistently allowed this paper to be my own work, but steered me in the right the direction whenever he thought I needed it.

I owe great thanks to the jury members of this thesis for accepting evaluating the present work and for their precise and efficient review of the complete thesis as well as for their interesting comments and very useful hints that allowed improving this manuscript.

I also appreciate the presence of Ms. Pilar Hernández, from FAO CopMed project, to the thesis defense and the encouragements and support she provided during this important day.



I am deeply grateful to Ms. Escutia Claudia for all her kindness, help and for her joy of life that she shares where she passes.

I take this opportunity to express gratitude to all GFCM staff for their help, kindness and valuable advices.

Finally, I must express my very [illegible] parents, my uncle, my sister and my friends for providing me with [illegible] encouragement throughout my years of study and [illegible] writing this thesis. This accomplishment [illegible] them. Thank you

Abstract

The Mediterranean Sea is not only a one of the world's biodiversity hotspot but also is considered as one of the most important fishing area playing a crucial socio-economic role. However, recent studies indicate a worrying state of its main commercial fisheries. In this respect, considerable efforts are deploying at regional level to improve the status of Mediterranean fisheries on which many millions of peoples depend and this through providing management recommendations, establishing multi-annual management plans and developing strategies. With the overall objective of performing an up-to-date deeper spatio-temporal diagnostic of Mediterranean stock status, the annual validated assessments by scientific experts were collected, from which the available current values and available times series of indicators of recruitment (R), of fishing mortality (F) and of stock biomass (SSB and TB) as well as the set of established reference points were extracted. The stock status analysis was provided applying different approaches (meta-analysis and stock-by-stock analysis), using several indicators applied at different scale of aggregation. Which allowed diagnosing the current and the temporal trends of status of main Mediterranean fisheries at regional and sub-regional level as well as pointing out the different state of functional groups and individual stocks. The findings of the present study clearly show that the Mediterranean assessed stocks are in a worrying status being the majority outside safe biological limits either in terms of biomass, exploitation or both criteria and that the degree vary among stocks, functional group and geographical sub-areas. It was revealed that the Western Mediterranean stocks are in the worst state compared to the others Mediterranean sub-regions. Among functional groups, the small pelagic showed the better status compared to demersal fish and crustaceans. Out of the 87% stocks subjected to the overexploitation ($F > F_{MSY}$), 21% are currently in a low overfishing level from them 33% of assessed stocks are so close to reach the target level and among the 69% of stock with biomass below the threshold empirical reference point, 12% are close to reach the reference point. Those stocks request only a least of 10% of fishing mortality reduction to shift their status from an overfishing to a rational exploitation. Among all examined individual stocks, the red mullet in the strait of Sicily showed the lowest relative biomass level. On other hand, some stocks are very hardly harvested such as the stock of hake in Gulf of Lions that is exploited around 13 times greater than the MSY level. The assessment of stock status based on a simultaneous analysis of the status of stock size and fishing mortality reflects better the status of stocks specially when it is presented on Kobe plot using both threshold and limit reference points. This kind of analysis provide more complete picture when it is enhanced with updated information on fishery such as the sensitive species habitats, fishing grounds, catch composition and historical landings.

Keywords: Mediterranean, sub-regions, stock status, indicators, reference points, functional groups, stocks

Résumé

La mer Méditerranée n'est pas seulement un "point chaud" de la biodiversité mondiale, mais elle est également considérée comme une zone de pêche jouant un rôle socio-économique notable. Cependant, des études récentes indiquent une aggravation de l'état de ses principales pêcheries commerciales. À cet égard, des efforts considérables sont déployés au niveau régional pour améliorer l'état des pêcheries méditerranéennes dont dépendent plusieurs millions de personnes.

Dans le but général d'effectuer un diagnostic spatio-temporel plus approfondi et actualisé de l'état des stocks méditerranéens, les évaluations des stocks annuelles validées par le Comité Scientifique Consultatif des pêches (CSC) de la (CGPM) et les STECF de la Commission Européenne (CE) ont été collectées, à partir desquelles les indicateurs de recrutement (R), de mortalité par pêche (F) et de biomasse de stock (SSB et TB) ainsi que l'ensemble des points de référence établis ont été extraits. L'analyse de l'état des stocks a été fournie en appliquant différentes approches (méta-analyse et analyse de stock-par-stock), en utilisant plusieurs indicateurs appliqués à différentes échelles d'agrégation. Ce qui a permis de diagnostiquer l'état actuelles et les tendances temporelles de l'état des principales pêcheries méditerranéennes au niveau régional et sous régional, ainsi que de souligner les différents états des groupes fonctionnels et des stocks individuels. Les résultats de la présente étude montrent clairement que l'état des stocks Méditerranéennes évalués est inquiétant étant la majorité en dehors des limites biologiques sûres soit en termes de biomasse, d'exploitation ou des deux critères et que le degré varie selon les stocks, le groupe fonctionnel et les sous-zones géographiques. Il a été révélé que les stocks de la Méditerranée occidentale sont dans le pire état par rapport aux autres sous-régions méditerranéennes. Parmi les groupes fonctionnels, les petits pélagiques ont montré un meilleur état par rapport aux poissons démersaux et aux crustacés. Sur les 87% de stocks soumis à la surexploitation ($F > F_{MSY}$), 21% sont actuellement dans un faible niveau de surpêche parmi eux 33% des stocks sont si proches d'atteindre le niveau cible et parmi les 69% des stocks avec une biomasse inférieur au seuil de référence empirique, 12% sont proches d'atteindre le point de référence établi. Ces stocks ne demandent qu'une réduction de la mortalité par pêche de l'ordre de moins de 10% pour passer vers une exploitation rationnelle. Parmi tous les stocks individuels examinés, le mulet rouge dans le détroit de Sicile a montré le niveau de biomasse le plus bas. D'autre part, certains stocks sont exploités sévèrement, comme le cas du stock de merlu du Gulf de Lions qui est exploité environ 13 fois plus que le niveau de MSY. L'évaluation de l'état du stock basé sur une analyse simultanée de l'état de la biomasse et de la mortalité par pêche reflète mieux sont état spécialement lorsqu'il est présenté sur le "Kobe plot" en utilisant à la fois les points de référence seuil et limite. Ce type d'analyse fournit une image plus précise et complète lorsqu'il est renforcé par des informations pertinentes et actualisée sur la pêcherie, tel que les habitats sensibles de l'espèce, les zones de pêche, la composition et les historiques des captures.

Mots-clés : Méditerranée, sous-régions, état du stock, indicateur, points de référence, groupe fonctionnel, stock.

Resumen

El Mar Mediterráneo no es solamente un "punto caliente" de biodiversidad mundial, sino se considera también como una zona pesquera que juega un papel socioeconómico muy importante. Del otro lado, estudios recientes indican un empeoramiento del estado de sus principales pesquerías comerciales.

Con el objetivo general de realizar un diagnóstico espacio-temporal más completo y actualizado del estado de las poblaciones mediterráneas, las evaluaciones anuales validadas por el Comité Científico Asesor de la Pesca de le CGPM y el STECF de la Comisión Europea (CE), a partir de los cuales se extrajeron los indicadores de reclutamiento (R), de mortalidad por pesca (F) y de biomasa del stock (SSB y TB), así como todos los puntos de referencia establecidos. El análisis del estado de la población se realizó mediante la aplicación de diferentes enfoques (meta-análisis y análisis de stock por stock), utilizando varios indicadores aplicados a diferentes escalas de agregación. Esto nos permitió diagnosticar las tendencias actuales y temporales en el estado de las principales pesquerías mediterráneas a nivel regional y subregional, así como detectar los diferentes estados de grupos funcionales y poblaciones individuales. Los resultados del presente estudio muestran claramente que el estado de las poblaciones mediterráneas evaluadas es preocupante, ya que la mayoría está fuera de los límites biológicos de seguridad en términos de biomasa, presión de explotación o ambos criterios y que el grado varía según los stocks, el grupo funcional y las subáreas geográficas. Se reveló que los stocks del Mediterráneo occidental están en el peor estado en comparación con las demás subregiones del Mediterráneo. Entre los grupos funcionales, los pelágicos pequeños mostraron un mejor estado comparado con los peces demersales y los crustáceos. Del 87% de los stocks sujetos a la sobreexplotación ($F > F_{MSY}$), 21% están actualmente en un nivel bajo de sobrepesca, entre ellas 33% están tan cerca de alcanzar el nivel objetivo y entre el 69% de stocks con biomasa por debajo del umbral de referencia empírico,12% están cerca de alcanzar el punto de referencia establecida. Estos stocks sólo requieren una reducción de la mortalidad por pesca de alrededor del 10% para avanzar hacia una explotación racional. De todas las poblaciones individuales examinadas, el salmonete del Estrecho de Sicilia mostró el menor nivel de biomasa. Por otro lado, se revela que algunos stocks son explotados muy intensamente, como es el caso del stock de la merluza del Golf de León, que se explota aproximadamente 13 veces más que el nivel de MSY. La evaluación de la situación del stock basada en un análisis simultáneo del estado de la biomasa y la mortalidad por pesca refleja mejor el estado, especialmente cuando se presentan en un diagrama de "*Kobe Plot*" utilizando ambos puntos de referencia umbral y límite. Este tipo de análisis proporciona una diagnosis más precisa y completado cuando se fortalece con información relevante y actualizada sobre la pesquería, como los hábitats sensibles de las especies, las zonas de pesca, la composición y la histórica de las capturas.

Palabras clave: Mediterráneo, subregiones, estado del stock, indicador, puntos de referencia, grupo funcional, población.

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Abbreviations and acronyms

AIS	Automatic Identification System
DCRF	Data Collection Reference Framework of the GFCM
E	Exploitation ratio (Z/F)
EcAp	Ecosystem Approach
EC	European Commission
EU	European Union
F	Fishing mortality
FAO	Food and Agriculture Organization of the United Nations
F_{MSY}	Fishing mortality rate of maximum sustainable yield
FRA	Fisheries Restricted Area
GFCM	General Fisheries Commission for the Mediterranean
GSA	Geographical Sub-Area
ICCAT	International Commission for the Conservation of Atlantic Tunas
IUU	Ilegal, Unreported, and Unregulated
MPA	Marine Protected Area
MED	Mediterranean Sea
MSY	Maximum Sustainable Yield
MSFD	Marine Strategy Framework Directive
RFOM	Regional Fisheries Management Organization
SAC	Scientific Advisory Committee on Fisheries
SAF	Stock Assessment Forms
SSB	Spawning Stock Biomass
STECF	Scientific, Technical and Economic Committee for Fisheries
TB	Total Biomass
UNEP/MAP	United Nation Environment Programme / Mediterranean Action Plan
VMS	Vessel Monitoring System
WGBS	Working Group On Black Sea
WGSA	Working Group On Stock Assessment
WGSASP	Working Group On Stock Assessment of Small Pelagic
WGSAD	Working Group On Stock Assessment of Demersal species
XSA	Extended Survivor Analysis

1. General introduction

1.1. Mediterranean and Black Sea fisheries

The importance of marine ecosystems

As the author Arthur C. Clarke said: “how inappropriate to call this planet Earth when it is quite clearly Ocean”. In fact, Seas and Oceans account for about 70% of its total surface and contain more than 90 % of all life on Earth (the World Bank, 2005).

The oceans and seas, including the Mediterranean Sea’s health may not be a top-of-mind issue for most people, however, it impacts directly and indirectly not only on everyone's well-being but also on their survival. In fact, marine ecosystems provide a considerable even vital service making the Earth habitable. These services were valuated at US$2.5 trillion (1). Among them, their big ability to capture and store carbon, to regulate weather and climate, to protect coastal areas from storm and to maintain the water cycle. Furthermore, as reported by Molnar *et al*., (2009), up to 50 % of the oxygen that humans and terrestrial animals breathe comes from the green marine organisms that tint seas and ocean’s surface; namely the algae. Therefore, as stated by Dr. Sylvia Earle: “no oceans, no us and no blue, no green” (2).

The Mediterranean and Black Sea presentation

The Mediterranean Sea can be described as an intercontinental sea given that is stretched from the Atlantic Ocean on the West to Asia on the East and separates Europe from Africa (Bianchi & Morri, 2000; Myers *et al.,* 2000; Coll *et al.,* 2010). It is formed by a several other smaller seas or basins among them the Alboran, the Adriatic, the Aegean and the Tyrrhenian seas, as well as the Algerian-Provence, the Ionian and the Levantine basins. In addition, it is the largest (2,969,000 km^2) and the deepest enclosed sea on earth with an average depth of about 1460 m and a maximum of about 5267 m (Coll, *et al.,* 2012; Psomadakis *et al.,* 2012). It is contributing with a 0.8% to the total world marine surface (Lleonart, 2008).

The Mediterranean is not an isolated sea. On the contrary, it is connected with the Atlantic via Strait of Gibraltar on the West and with the Red Sea through Suez Canal on the southern part. Furthermore, it connected with the Sea of Marmara and the Black Sea through the strait of Bosphorus in the North-east part (Coll *et al.,* 2012). As pointed out by Coll *et al.,* (2012), the Strait of Sicily divides it into two distinct basins, the Western (0.85 million km^2) and the Eastern (1.65 million km^2). They are separated by the Strait of Messina and by the channel between Sicily and Tunisia, where the depth of the ridge joining Sicily and Africa is only 400 meters (Fig.1).

Its waters lost by the evaporation process are not equally compensated by the precipitation or other inputs. According to Lleonart and Maynou (2003), thanks to the contribution of the Atlantic water, through the strait of Gibraltar, these losses are relatively balanced. However, the Mediterranean water salinity still high compared with other oceans and seas. Other studies showed that this salinity increases gradually from the Western to the Eastern part. The Mediterranean has a large area of open water and a relatively narrow continental shelf only the Adriatic, the Gulf of Lions, the Gulf of Gabes and the North of the Black Sea have large continental shelves (Lleonart, 2008).

The Black Sea is known as the most isolated sea on earth (Öztürk, 2010). Indeed, on the southwest, the Black Sea is connected with the Mediterranean through Bosporus, the Sea of Marmara and the Dardanelles. On the northeast, it is connected to the Sea of Azov (Fig.1). The Black Sea totalizes a surface area of about 423 000 km2 with a maximum depth around 2 212 m (Bradai *et al.,* 2012). It is surrounded by Turkey, Bulgaria, Romania, Ukraine, Russia and Georgia (Coll *et al.,* 2010).

The most striking characteristics of the Black Sea are the high level of hydrogen sulphide (H2S), the presence of a permanent halocline between 150 and 200 m (Bradai *et al*., 2012) and by the high river discharge into a relatively small semi-enclosed Sea. Moreover, The Black Sea is characterized as a water body with very low ecological environmental capacity, because it contains the largest anoxic water mass on our planet below a depth of 150-200 meters (Öztürk, 2002) and it has a poor water exchange with the adjacent seas through the narrow straits and poor vertical exchange with the deep hydro-sulphide layer (Tokarev & Shulman, 2007).

The Black Sea average surface salinity is about 18–18.5 per mille during winter, and increases by 1.0–1.5 per mille in summer. The mean annual surface temperature varies from 16°C in the south to 13°C in the northeast and 11°C in the northwest (Öztürk, 2010).

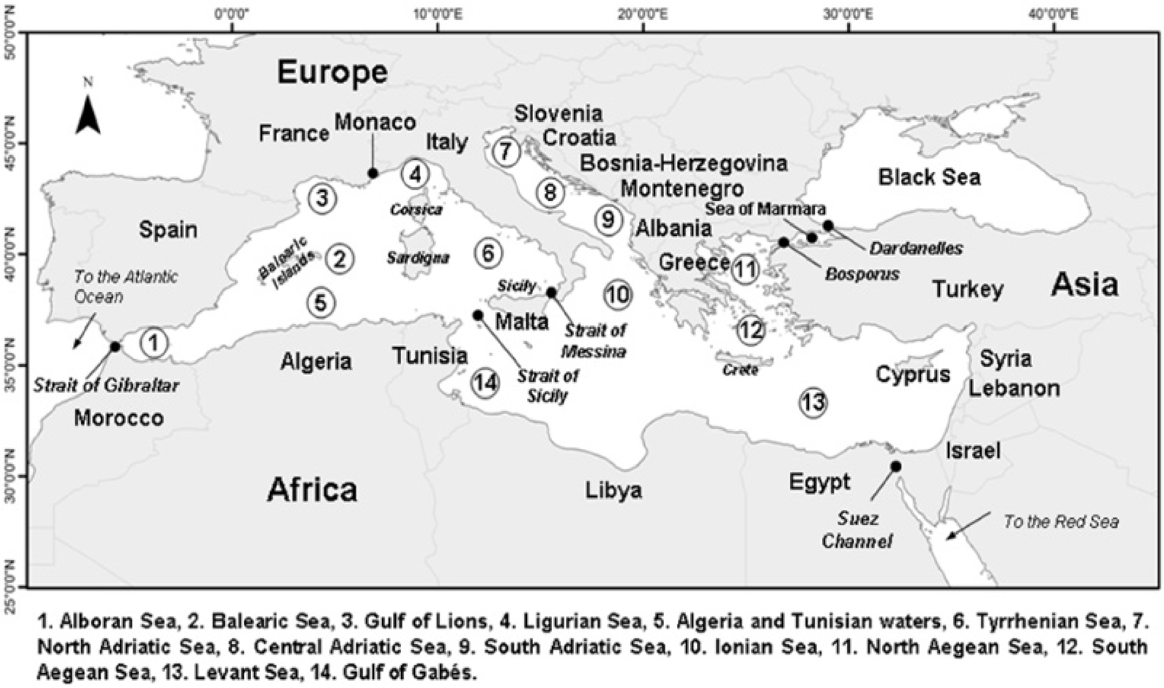


Figure 1: Map of the Mediterranean and Black Sea (Coll *et al*., 2010).

The Mediterranean and Black Sea features

The Mediterranean Sea has typical features that make it a distinct and an important sea from diverse angles and aspects. In fact, the Mediterranean is distinguished by its considerable biodiversity with which it broke world records. Even though it represents only a 0.82% of the world's ocean surface, it harbors between 4% and 18% of the world's marine species according to Bianchi and Morri (2000) and constitutes one of the 25 hotspots of biodiversity worldwide, where an exceptional high level of endemic species is hosted according to Meyers *et al.,* (2000) and UNEP-MAP RAC/SPA (2010). Moreover, Coll *et al*., (2010) reviewed all the available publications on the Mediterranean biodiversity and they conclude that within this sea 17,000 marine different species are hosted, although this study was not exhaustive and some environment is still poorly known, as deep oceans, deserts, etc.

It was revealed that the Mediterranean biodiversity is more concentrated along its coastal areas and continental shelves, and strongly decreases with depth (UNEP-MAP RAC/SPA, 2010). As it is illustrated by Danovaro *et al.,* (1999) and confirmed by Coll *et al*., (2010), the Mediterranean biological production not only decreases from the North to the South and the West to the East but it is also inversely related to the increase in temperature and salinity and it is differentially distributed among its sub-regions: 87% of creatures lives in the Western Mediterranean, 49 % in the Adriatic Sea and 43% in the Eastern Mediterranean (UNEP-MAP RAC/SPA, 2010). Which illustrates the considerable geographical heterogeneity of Mediterranean Sea biodiversity and production.

Furthermore, the Mediterranean Sea is home to rare and typical marine habitats that contribute significantly to increase the habitat structural complexity allowing in fulfil an important ecological role required for the renewal and survival of many species, notably nursery, feeding, and /or reproductive functions (Colloca *et al.,* 2004; Ordines and Massuti, 2009). The key zones that constitute the Mediterranean biodiversity hotspots are especially located in the coastal areas. Among them, *Posidonia oceanica* meadows, the coraligenous communities (*Corallium rubrum, Lophelia pertusa* and *Madrepora oculata…*), the Cystoseira forests, the *Lithophyllum byssoides* rim, the vermetid platforms and the concretion with *Neogoniolithon brassica-florida* (UNEP-MAP RAC/SPA, 2010). In addition, its deep-sea hosts important habitats of many fishes and decapod crustaceans, including the underwater canyons, the seamounts and the deep-sea coral reefs (UNEP-MAP RAC/SPA, 2010-a; Gubbay *et al.,* 2016). Moreover, a vast part of its high seas characterizes by oceanographic features such as currents, fronts and upwellings, where pelagic species are concentrated, including, the high migratory fishes (UNEP-MAP-RAC/SPA. 2010-b).

On the other hand, the Black Sea biodiversity is low compared with that of the Mediterranean Sea mainly due to anoxia in large parts of their deeper waters. Furthermore, the Black Sea marine ecosystems structure differs from the neighboring Mediterranean Sea not only by the species variety but also by the list of dominated groups (EEA, 2002). Indeed, the gradual increase of temperature during the history (last 10 000 years) has facilitated the penetration of Mediterranean species in the Black Sea. Today, 80 percent of the total fauna in the Black Sea are Mediterranean origin (Ozturk, 2010; Bradai *et al.,* 2012).

The fisheries exploitation and importance

Since ancient times, man has faced the ocean force to explore it and particularly to extract food, so he started harvesting fisheries, since then and with time fishing activities become an integral part of human society. Indeed, after relying on its muscle-power for so long, humankind found a way to tap into the energy buried deep in the Earth. This energy coupled with his intelligence were the driving force of the continuous improvement in fishing activities allowing him to design fishing gears more and more elaborated, bigger and efficient, and to acquire fishing and navigation tools more powerful and efficient as well. The technological advances permit him harvesting both the onshore and the offshore, accessing deeper areas, pinpointing the marine resources exact location and reducing wasting time for looking for fish. Moreover, the development in refrigeration, notably the ice –making and fish processing equipment resulted in designing a new generation of vessels capable of remaining at sea for extended periods (FAO, 2016-c). Thus, gradually seas and oceans turn out to be not only a mean of subsistence but also an economic activity more and more profitable and valuable. Currently, fishing activity is no longer a question of family but investment and technology.

Nowadays, fisheries and aquaculture sector has a considerable importance at world scale as many millions of people around the world find in it a source of income and livelihood. As the FAO stated in FAO (2016-b), the global fishery production was 93.4 million tons in 2014 against 11.9 million tons from inland waters. In addition, the FAO (2016-b) reported that the total number of fishing vessels in the world in 2014 is estimated at about 4.6 million and the people engaged in the primary sector of capture fisheries and aquaculture in 2014 up to 56.6 million, this number become enormous when the depending sectors are considered. Moreover, fish and fishery products represent one of the most-traded segments of the world food sector, with about 78 percent of seafood products estimated to be exposed to international trade competition (FAO, 2016-b).

The FAO fishing area 37 (Mediterranean and Black Seas) is considered one of the most important fishing area in the world, where fishing activities have an enormous cultural, social and economic importance (OCEANA, 2016; FAO, 2017). This sea contributes significantly to food security by supplying a considerable quantity of animal protein to at around 464 million Mediterranean people, its production was around 1056422 tons in 2014 (3). Indeed, despite the smaller proportion of the Mediterranean production, the main prices of its landings are well above the average prices of world markets (Lleonart and Maynou 2003). According to the most recent data (FAO, 2016-a), the value of the Mediterranean and Black Seas landings is up to US$ 3 094 000 000, while their regional economic impact is 2.65 times greater than the value at first sale, equivalent to US$6 954 000 000. Likewise, the fishing activity in this area plays a particular role in the employment. As stated in FAO (2017-a), around a quarter of a million people are directly employed onboard fishing vessels in this region and when the indirect employments are included the number rises exponentially. Moreover, this activity supports 60% direct jobs in the Southern and Eastern Parts of the basin, where the most vulnerable populations are located (FAO, 2016-a, FAO, 2017-a). As illustrated in Sauzade and Rousset (2013), over 55% of this workforce is operating in small-scale fisheries, which not only support the employment in the southern rim of the Mediterranean but also play an important role in the social fabric and cultural identity of many Mediterranean coastal regions. More than that, the well-being of 150 million people who live around the Mediterranean shores depend on the sustainability of Mediterranean fisheries (WWF, 2015).

The characteristics of Mediterranean and Black Sea fisheries

The Mediterranean Sea, including the Black Sea, was described as a complex fishing area due to the multi-species nature of its exploited stocks and the high variety of fishing methods and fleet segments operating there (SGMED, 2004). The most recent data reports that within the GFCM area of application, more than 92 700 vessels are operating, encompass the small-scale, the semi-industrial and the industrial vessels involving many fleet segments; the former type accounts for about 80% of the total, from which the highest number is detected in the Eastern and Ionian sub-regions (FAO, 2016-a). The purse seiners (> 12 m LOA) are by far the main contributor to the regional total landing with a percentage up to 41%, followed by the trawlers (12–24 m LOA) and the small-scale fisheries. In the contrast, the trawlers longer than 12 m LOA record the largest landing value in this area, which up to 38 percent of the total, followed by the purse seiners longer than 6 m LOA and the polyvalent small-scale vessels up to 12 m LOA with a contribution estimated at about 27% and 22%, respectively. Except who target on the large pelagic (e.g. tuna, swordfish), generally the Mediterranean and Black Sea fleets operate from their homeports (Sauzade and Rousset, 2013).

As it is mentioned above, the Mediterranean is characterized by its multi-species fisheries and by the lack of mono-specific stocks, which obviously linked to the high biodiversity of this Sea (Lleonart, 2008, FAO, 2016-a) and resulted in the multispecies catch composition. Its fisheries can be divided into three main groups, namely (i) the large pelagic, (ii) the small pelagic and (iii) the demersal species, which encompasses the fishery of deep-sea crustaceans and multispecies demersal fishery (Lleonart, 2008). By far the small pelagic dominate the others and constitute the main contributor to the total landing (Cury *et al.,* 2000; Coll *et al.,* 2006a; Palomera *et al.,* 2007; Banaru *et al.,* 2013; FAO, 2016-a). As stated in Lleonart (2008) and confirmed in FAO (2016-a), Sardine and Anchovy contribute to up to 50% to the recorded annual total landing.

The demersal species represent about 30% of total annual reported catches in the Mediterranean and Black Sea (4). The demersal species are very diverse and none of them counts more than 3% of total catch. Indeed, more than 100 demersal species are caught in this area being the most economically important among them, European hake (*Merluccius merluccius*), Red mullets (*Mullus spp.*), Blue whiting (*Micromesistius pautassou*), Whiting *(Merlangius merlangus*), anglerfishes (*Lophius spp.),* Cuttlefish (*Sepia officinalis*), Red shrimps (*Aristeus antennatus* and *Aristoemorpha foliacea*), Norway lobster (*Nephrops norvegicus*) and Deep water rose shrimp (*Parapenaeus longirostris*).

In the Mediterranean and the Black Sea, the shared stocks constitute a minority compared to the other exploited stocks (Sauzade and Rousset, 2013), however, these stocks are often shared among fleets from different neighboring countries (FAO, 2016-a).

Concerning the Mediterranean and Black Sea historical seafood production, it was multiplied from the beginning of the 70s to the start of 80s, where it rose from about 1 to 2 million tons (FAO, 2016-a; Fig.2). Afterwards, it remained relatively stable for many years before declining deeply in 1989 and 1990 as a result of small pelagic collapse in the Black Sea, since then it has declined by 25% and remained rather constant (Tsikliras *et al*., 2013).

The Mediterranean production, excluding the Black Sea landings, was increased strongly from the 50s to the beginning of the 80s raising from 420 000 tones to approach 1 000 000 tons. Then, it continued increasing until reaching its historical peak about 1 128 000 tons in 1995 (Sauzade and Rousset, 2013). Since that time, however, the catches follow a continuous and irregular decline except in 2006 when a peak was recorded, especially due to an exceptional catch of small pelagic (Sauzade and Rousset, 2013).

In 2013, the Mediterranean and Black Sea totalized a production of about 1163 000 tons, from which the Mediterranean was contributed with about 60 % (FAO, 2016-a).

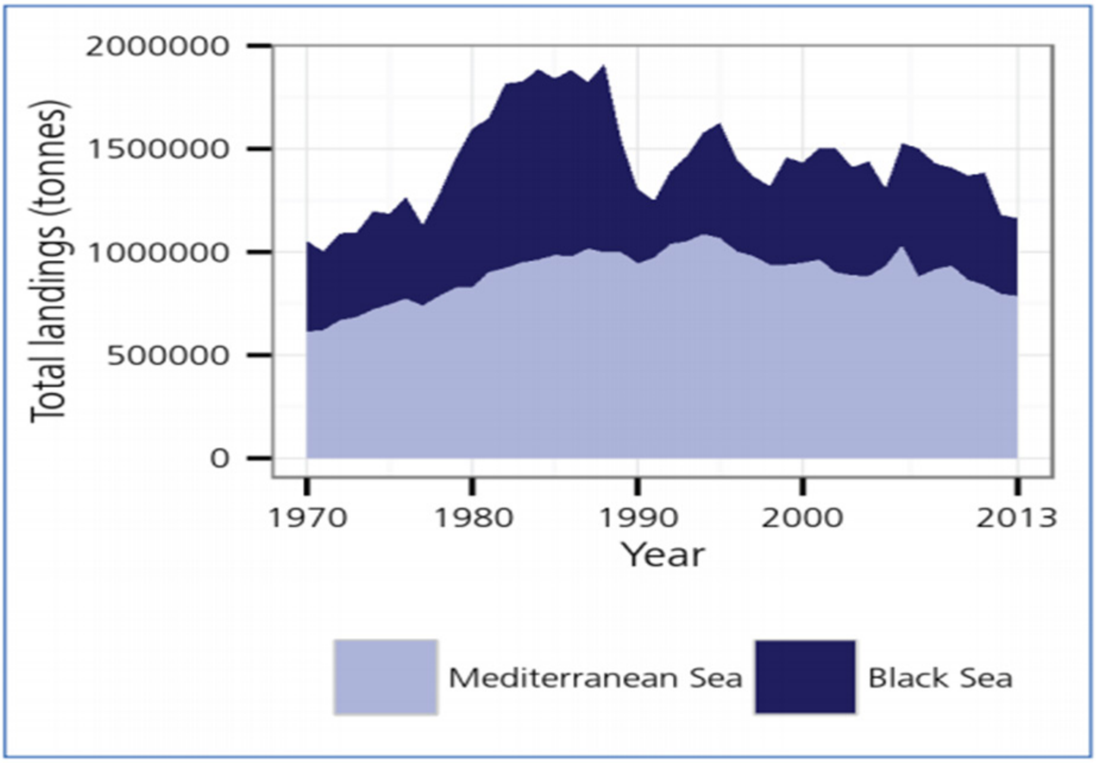


Figure 2: Trends in cumulative landings in the Mediterranean and the Black Sea between 1970 and 2013 (FAO, 2016-a).

The production of the small-scale fisheries is destined to the local markets, while the other segments tend to export their catches (Sacchi, 2011). Indeed, the Mediterranean and Black Sea fish and seafood are largely accepted and appreciated by the markets. Moreover, their products that are generally commercialized mainly fresh sold with relatively high prices (Kirkegaard *et al*., 2008).

The status of Mediterranean and Black Sea resources

Fascinated by its enormous size, for centuries humans believed that oceans in general and the Mediterranean Sea in particular would provide an unlimited supply of fish, even Aristos never thought that one day the oceans will run out of its biological resources. In fact, the Earth, include Oceans and Seas were formed four milliards years ago, and the humans were only appeared almost 200 thousand years ago (King, 2010). On the other hand, his insatiable desires and short-term vision managed to destroy the biological and ecological balance essential to keep marine resources sustainability, putting them in a very awkward position and hence the livelihood of the following generations as well. Currently, the catches are stabilized (FAO, 2016-b), biological limits are exceeded, habitats are destroyed, top predators are under extreme pressures, marine resources are wasted and vulnerable species are killed without good reason. In this ocean, from the microorganism to the top predators, each species has a key role to play. None is futile or harmful.

The most recent studies proved that most worldwide fisheries signaled the alarming decline and, even, some ecosystems are stressed while other are threatened to be pushed to a point of no return if the marine resources will continue to be exploited irresponsibly (Athanassios *et al.,* 2015).

Mediterranean and Black Sea stocks status are not far from the state of worldwide fisheries, even it is worst given that the vast majority of stocks are declared overexploited. In fact, within this area the overexploitation was evident since the 1950, when about 60% of the Mediterranean and Black Sea stocks were reported as being fully exploited and 40% as overexploited (Froese *et al.,* 2002). According to FAO (2016-a), about 85 percent of Mediterranean and Black Sea assessed stocks are fished at biologically unsustainable levels. Furthermore, 96% of stocks fished exclusively by EU countries are exploited above what is considered sustainable (COM, 2015). Likewise, it was recently proved that the exploitation ratio has increased steadily and selectivity has deteriorated, thus leading to shrinkage of fish stocks (Vasilakopoulos *et al.,* 2014) and rapid decline of large predators, such as sharks (Ferretti *et al*., 2013; Fortibuoni *et al*., 2016).

The demersal stocks shown a worse state compared to small pelagic that is harvested, in average, close to the target (Sauzade and Rousset, 2013; FAO, 2016-a). Considered combined, the Mediterranean stocks are exploited 2.5 times more than the sustainable level. More than that, fishing mortality exceeds five times the level that can produce the maximum sustainable yield for European hake (*M. merluccius*) stocks that is exploited in some areas 12 times more that the level the can ensure the stocks sustainability (FAO, 2016-a).

1.2. Mediterranean and Black Sea fisheries management

An appropriate regional management of the Mediterranean and Black Sea common good are required to continue taking benefits and keeping both fish species and marine ecosystems as a whole in good health in the present and for future generations. In this regard, the General Fisheries Commission for the Mediterranean (GFCM) was established as a Council in 1949 under the provisions of Article XIV of the FAO Constitution, which gives it the full authority and competence over the Mediterranean and the Black sea as well as the power to adopt annually binding recommendations (FAO, 2016-d).

To undertake its work efficiently by focusing on small pelagic and demersal stocks, the GFCM delegated the management of the Mediterranean large pelagic fisheries (tunas and tuna-like species) to the International Commission for the Conservation of Atlantic Tunas (ICCAT). Aware of the great importance of not only maintaining cooperation between the two institutions but also strengthening it, the GFCM/ICCAT Working

Group on Large Pelagic Species was established in 1989 (FAO, 2006). Indeed, the stock assessments performed by this working group are regularly reviewed and analyzed by GFCM Subcommittee on Stock Assessment (SCSA) (5).

Besides the GFCM management, the European Mediterranean fisheries belonging to the European union states are also governed by the European Common Fisheries Policy (CFP) applied by the European Commission (Cardinale and Scarcella, 2017), which seeks to ensure high long-term fishing yields for all stocks by 2015 where possible, and at the latest by 2020 (6). In addition to the regional management, the Mediterranean and Black Sea fisheries (except whose belonging within the international waters) are subject to the sovereignty of the coastal States and managed, therefore, by the national jurisdiction ensured by international law and the United Nations Convention on the Law of the Sea (LOS Convention, 1982; European Parliament (2009).

No quotas and TACs are implemented for Mediterranean stocks, except for the Bluefin tuna (*Thunnus thynnus*) and, recently, for Swordfish fishery (*Xiphias gladius*) (OCEANA, 2016-b; ICCAT, 2016), and recent attempts to set up a maximum catch limit for sardines and anchovies in the Adriatic Sea (FAO, 2017-b). Therefore, the management of Mediterranean and Black Sea stocks is mainly based on the input control, i.e., fishing effort regulations supported by technical measures such as gear regulation, establishment of a minimum conservation reference size and areas and season closures (Colloca *et al.,* 2013; FAO MedSudMed, 2013; Vasilakopoulos *et al.,* 2014; Cardinale and Scarcella, 2017).

However, despite all the efforts especially made by the Regional Management Organizations, the Mediterranean main stocks remain in in worst state. As argued in FAO (2017), from 2004 onwards alone, 50 decisions have been taking by GFCM including binding recommendations. These decisions coupled with other works were resulting in the implementation of many management measures and strengthening the international collaboration on research, improving information exchange and determining the state of resources (FAO, 2016-a), on the other hand, no evident signs of improvement in the state of marine resources are detected, in contrast to many worldwide fisheries (WWF, 2016; Cardinale and Scarcella, 2017).

This delicate situation is related to different factors; firstly, those linked to the complexity of Mediterranean system, including the geopolitical complex situation, the artisanal nature of the fleet exploiting the resources, the multispecies stocks, and the high heterogeneity between its sub-regions in terms of development, policies, and knowledges on stock assessments. Secondly, the ineffectiveness of management measures to control the fishing mortality applied to the stocks is of a particular concern (Cardinale and Scarcella, 2017). Another crucial factors behind this plight were detected, mainly the issue of enforcement of management measures at national level as well as the few adherence to scientific advice, which manifest especially in the non-respect of minimum landing size (Colloca *et al.,* 2013), the loss of some key Mediterranean habitats, the exposition of nursery and spawning areas to high fishing pressure (Mouillot *et al.,* 2011), the waste of marine resources by the discard and the bycatch of vulnerable species (FAO, 2016-a). In addition, the potential environmental stress is a crucial element to consider and also the need for time for stocks to react to recent measures. And finally appears the issue linked to the implementing the recommendations at national level and enforcement (Cardinale and Scarcella, 2017).

Aware about all those challenges, the GFCM, as the main manager of this resources, passed by many reforms since its creation. In fact, for strengthening their role and enhancing their performance, four amendments were occurred (in 1963, 1976, and 1997 and in 2014). Indeed, from 2004 onwards, year coincided with the entry into force of the third amendment, GFCM was provided with some powerful tools allowing in enhancing the decision making in its area of application and make tangible actions, namely the establishment of a dedicated Secretariat and having an autonomous budget paid by their Members, the reinforcement of its Scientific Advisory Committee on Fisheries (SAC) and the creation of a new subsidiary bodies such as the Compliance Committee (CoC) and the Working Group on the Black Sea (WGBS). Moreover, in 2009 the commission was launched a performance review over a three-year period of consultation resulting in the modernization of the commission through the adoption of a set of amendments.

As a response to the increasing challenges and the apparent threats that face the sustainability of Mediterranean resources, two new approaches were adopted recently (in 2014) by the commission, namely *(i)* the implementation of the multiannual management plans and *(ii)* the adoption of the sub-regional approach to fisheries management that takes into account the shortcomings and particularities of each sub-region, which will allow focusing the work on the priority topics for the sub-region and get, hence, a better results.

In this circumstance, the GFCM engaged in the establishment of an ambitious strategy adopted by the commission in 2016, so-called Mid-Term Strategy (2017-2020). The major purpose of this strategy is to improve, by 2020, the sustainability of Mediterranean and Black Sea fisheries, by achieving five targets and related outputs and actions, including to "reverse the declining trend of fish stocks through strengthened scientific advice in support of management" (Target 1). In fact, three outputs involved under the target 1 as emphasis the Fig.3, mainly: i) enhanced knowledge and expertise on Mediterranean and Black Sea fisheries; ii) socio-economic information and analysis incorporated into scientific and management advice; iii) enhanced science-based GFCM regulations on fisheries management. The meet of the underlined target (Target 1) requires performing an overall analysis of all validated assessments of Mediterranean stocks and clearly represent stock status at regional level as well as their temporal trend (FAO, 2017-a).

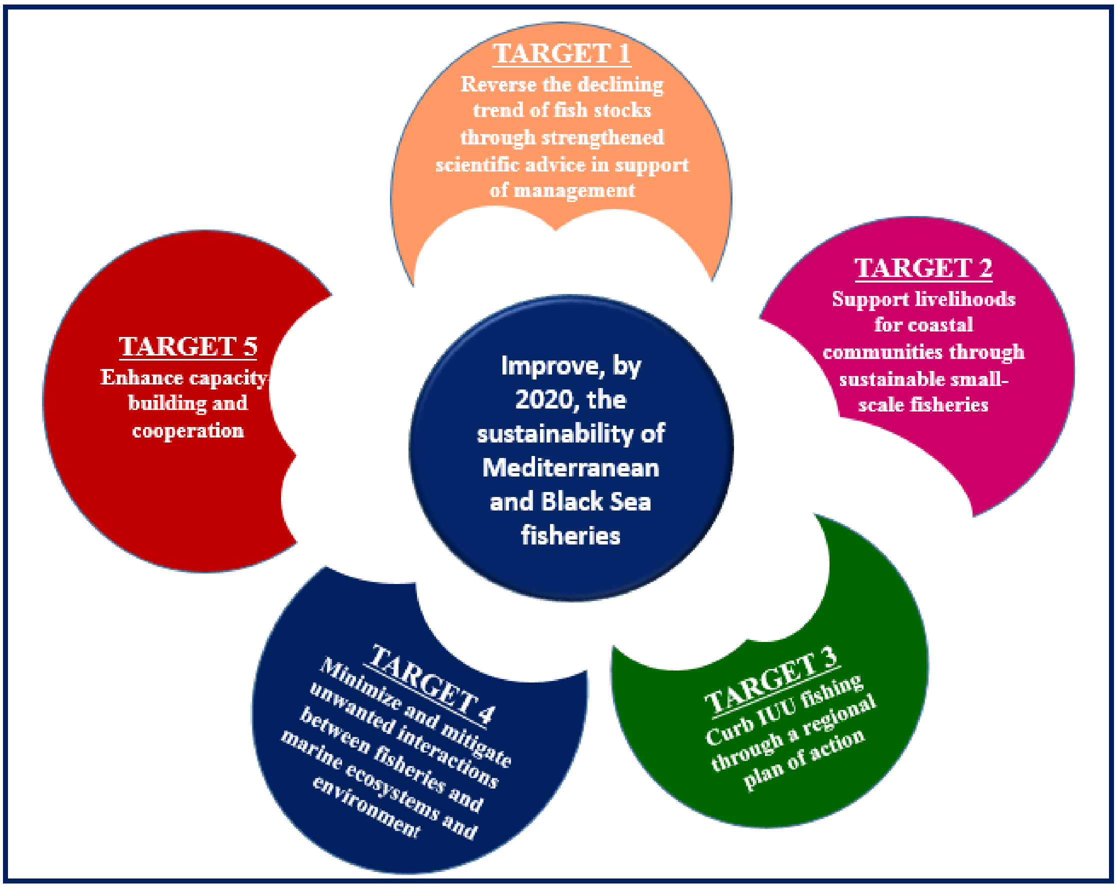


Figure 3: The five targets of GFCM Mid-term strategy (2017-2020) (FAO, 2017-a modified).

1.3. Providing scientific advice within GFCM approach

To fulfill its mission and to meet its overall objective, GFCM regularly reviews and assesses the status of living marine resources belonged within its area of application through its technical bodies, mainly the Scientific Advisory Committee on Fisheries (SAC) in the Mediterranean Sea and the Working Group on Black Sea (WGBS) in the Black Sea and their subsidiary bodies. In fact, during the commission annual meeting the SAC chairman and the WGBS coordinator provide the commission with advice from subsidiary bodies on topic of relevance for the region such as the marine environment and ecosystems, statistics and information, stocks requiring precautionary or emergency measures and other sub regional activities. Based on these elements and in consultation with their member states, through the national delegates, and considering the intervention of several observers and partner organizations, including Non-Governmental Organizations (NGOs), the commission takes the management decisions necessary to ensure the sustainability of living marine resources (Fig.4) (FAO, 2017-b).

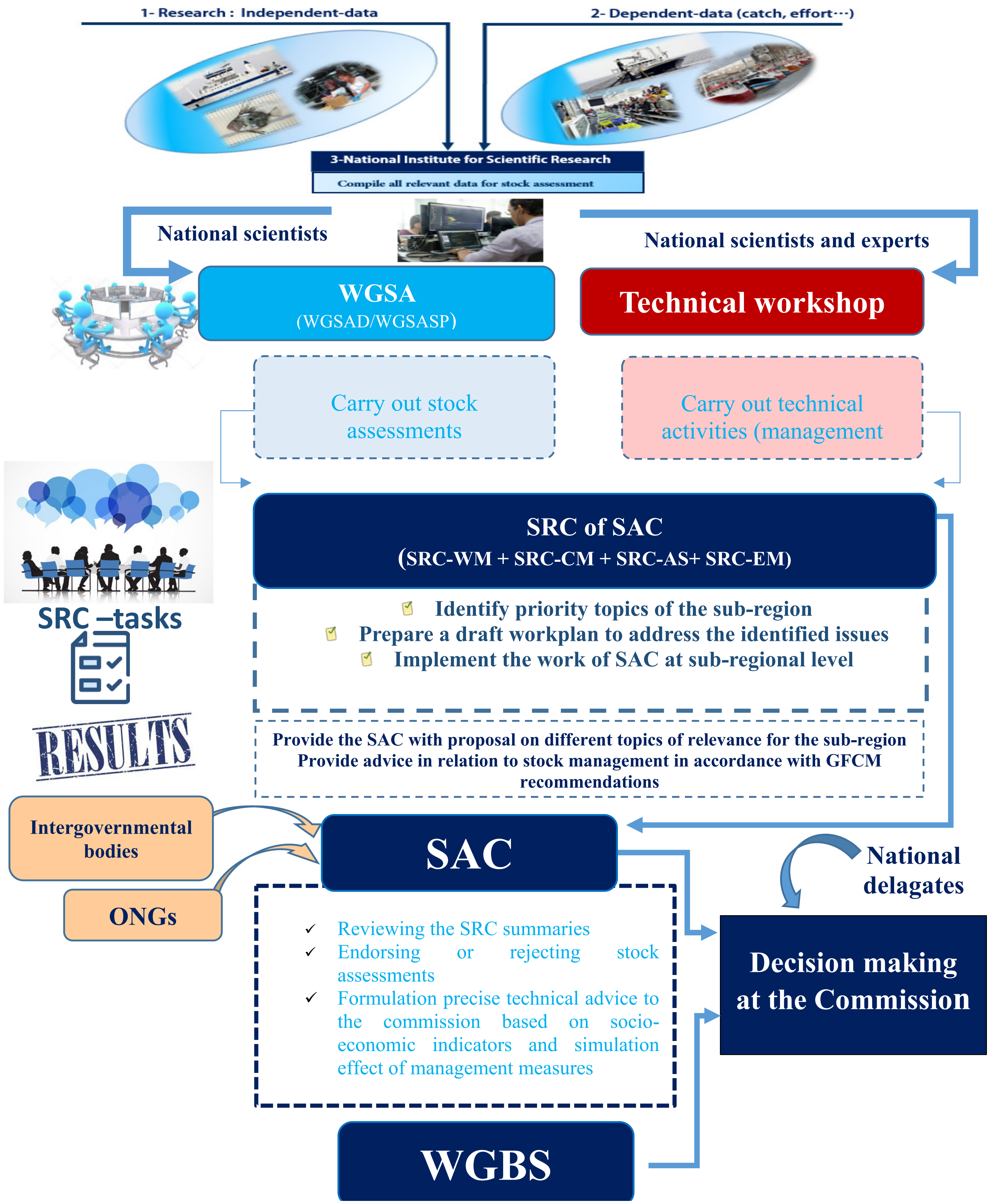
In fact, the SAC was created in 1967 with the mandate to provide the commission with independent advice on the technical and scientific basis for decisions related to fisheries conservation and management, including biological, social and economic aspects (7). To meet that, the SAC operates through five subsidiary bodies, among them the Working Group on the Assessment of Small Pelagic (WGASP) and Demersal species

(WGAD) that are in charge of carrying out stock assessments and providing scientific advice (GFCM, 2016-a; GFCM, 2016-b). In addition, when necessary, the ad-hoc technical workshops are organized on a case-by-case basis to address some specifics technical aspects identified by the SAC (GFCM, 2017-b).

Moreover, to strengthening their subsidiary bodies, at its thirty-ninth session (Italy, May 2015), GFCM was took a decision in amending the reference framework of its subsidiary bodies, whereby the SAC tested a shift from a thematic to a sub-regional approach in implementing its mandate during a two-years (2015–2017) feasibility study. In this regard, the SAC was supported by four Regional Sub-Committees (SRCs) operating through the Mediterranean Sea (i.e. Western Mediterranean, Central Mediterranean, Eastern Mediterranean and Adriatic Sea) (Fig.4). The SRCs consist on technical fora in which experts from both scientific institutes and fisheries administrations are invited to discuss and express their technical views on sub-regional issues of relevance.

This new adopted approach allowed the SAC and, therefore, the GFCM to identify the relevant matters and specificities of each sub-region that are better taken into account and discussed, mainly among countries and stakeholders directly concerned by their implementation. Moreover, participation had improved in terms of expertise, country representation and partnerships (GFCM, 2017-b).

In addition, with the adoption of the ambitious Mid-term strategy (2017-2020) that is designed to face numerous new challenges facing the sustainability of Mediterranean and Black Sea fisheries, the SAC is requested to provide more precise technical advice basing on the socio-economic indicators as well as the evaluation of the potential effects of management measures on the fisheries (FAO, 2017-a). Furthermore, a new approach was adopted to deal with stocks with fragmented or not enough data that are required to provide a technical advice. This approach consists on taking a precautionary advice and launching, in parallel, immediate actions to collect the needed data and information (FAO, 2017-a)


1- Research : Independent-data
2- Dependent-data (catch, effort…)
3-National Institute for Scientific Research
Compile all relevant data for stock assessment
National scientists
National scientists and experts
WGSA
(WGSAD/WGSASP)
Technical workshop
Carry out stock assessments
Carry out technical activities (management
SRC of SAC
(SRC-WM + SRC-CM + SRC-AS+ SRC-EM)
SRC –tasks
Identify priority topics of the sub-region
Prepare a draft workplan to address the identified issues
Implement the work of SAC at sub-regional level
RESULTS
Provide the SAC with proposal on different topics of relevance for the sub-region
Provide advice in relation to stock management in accordance with GFCM recommendations
Intergovernmental bodies
ONGs
SAC
National delagates
Reviewing the SRC summaries
Endorsing or rejecting stock assessments
Formulation precise technical advice to the commission based on socio-economic indicators and simulation effect of management measures
Decision making at the Commission
WGBS

Stock versus GSA

Although it is difficult to give a clear definition of a concept of stock *(*Lleonart, 2015*)*, some trials were made. Indeed, the NOAA defined the stock as a "*group of fish of the same species living in same geographic area and mix enough to breed with each other when mature*". This concept was introduced by FAO (2003) as a "*set of survivals of the cohorts of a fishery resource, at a certain instant or period of time, expressed in term of biomass or numbers"* (NOAA, 2012).

The need to compile data, monitor fisheries and assess fisheries resources in a georeferenced manner has pushed the GFCM to divide its area of competence -that corresponding to FAO major fishing area 37- into 30 Geographical Sub-Areas (GSAs) which can be aggregated into four sub-regions (FAO, 2009). In fact, the GSA delimitation is mainly based on practical considerations (i.e. political and statistical (FAO, 1999 in Lleonart, 2003)) rather than on the stock distribution. Indeed, many stocks extend beyond the geographic limits of GSAs (SAC, 2014). Nonetheless, in the Mediterranean, the assessment is often performed by management unit –GSA- (FAO, 2016-a). They are also adopted for assessments at national level (Kirkegaard *et al.,* 2008).

Furthermore, the GFCM Working Group on Stock Assessment of Demersal species (November 2016) recommended giving attention to stock unit aspect when assessing stock status. The need to improve the knowledge on the stock boundaries and its relationship with the GSA in the Mediterranean was also stressed (GFCM, 2014).

Given that stock may cover several different management unit, performing stock assessment by GSA does not ensure that the whole stocks is assessed (FAO, 2016-a). A joint assessment using data from several GSAs is encouraged when scientific information proves that a stock is belong within more than geographical subarea.

Assessment of Mediterranean and Black Sea fisheries

As introduced above, the GFCM assesses routinely both European and non-European Mediterranean and Black Sea fisheries through its Scientific Advisory Committee on Fisheries (SAC) working groups, notably the Working Group on Stock Assessment of Demersal species (WGSADS) and Small pelagic (WGSASP) using the most appropriate methods taking into account data availability. Those working groups are formed by GFCM members' national scientists. Moreover, in this region the status of fish stocks exploited by European countries are also assessed by the Scientific, Technical and Economic Committee for Fisheries (STECF) of the EU. In fact, the STECF created a dedicated sub-body in charge of Mediterranean fisheries assessments, i.e. the Expert Working Group on Assessment of Mediterranean Sea stocks (MedEWG) which its mandate includes the stocks exploited by the EU Member Countries in the Mediterranean Sea. In addition, GFCM made a considerable effort to enhance the development of assessment on shared stocks between European and non-European countries with cooperation of the FAO regional projects too (FAO MedSudMed, 2013).

Including assessments performed by both organization, a limited number of stocks are assessed due to several causes, among them the big issue of data collection, include dependent and independent data (Fig.5).

In fact, two regular scientific surveys are conducted in the European Mediterranean water on an annual basis and their program as well as their protocol are included in the European DCF. The first one evaluates the demersal resources using the standardized trawl as a sampling gear and target a several number of species, it is the MEDiterranean International Bottom Trawl-Surveys (MEDITS). The main objective of MEDITS is to obtain abundance indices that are comparable between the different studied areas. This has been made possible by the standardization of the methodology (Lleonart and Maynou, 2003). The other survey is dedicated evaluating the small pelagic using the acoustic (Abad *et al.,* 1996; Patti *et al.,* 2000; Guennegan *et al.,* 2000), it is called MEDIAS -abbreviation of MEDIterranean Acoustic Survey. This survey mainly targets on sardine and anchovy stocks, which the vast majority are well covered (Lleonart and Maynou, 2003).

However, these standardized surveys, MEDIAS and MEDITS, are mainly adopted by European, countries. Therefore, the scientific surveys are conducted only in few GSAs of the Mediterranean waters. This issue is further complicated with the fact that the MEDIAS survey is only focus on Sardine and Anchovy stocks. In effect, some non-European countries have tried to implement national scientific surveys to evaluate their resources others are adopted recently MEDITS protocol but numerous countries still suffer from the lack of biological data due the absence of surveys.

Aware about these big issues that face the gain of knowledge of biomass level and distribution as well as the urgent need to join and harmonize the ongoing surveys in the rest of Mediterranean and Black Seas, GFCM engaged to deal with this challenge through the establishment of a regional trawl and acoustic surveys for the demersal species and small pelagic, successively (GFCM, 2017-b). Moreover, GFCM putted into disposal of its member states a Data Collection Reference Framework (DCRF) manual. This manual aims to help its member countries to collect more efficiently the relevant data on fisheries and aquaculture and its submission to the GFCM in a standardized way, which will contribute to empower the relevant GFCM subsidiary bodies with data

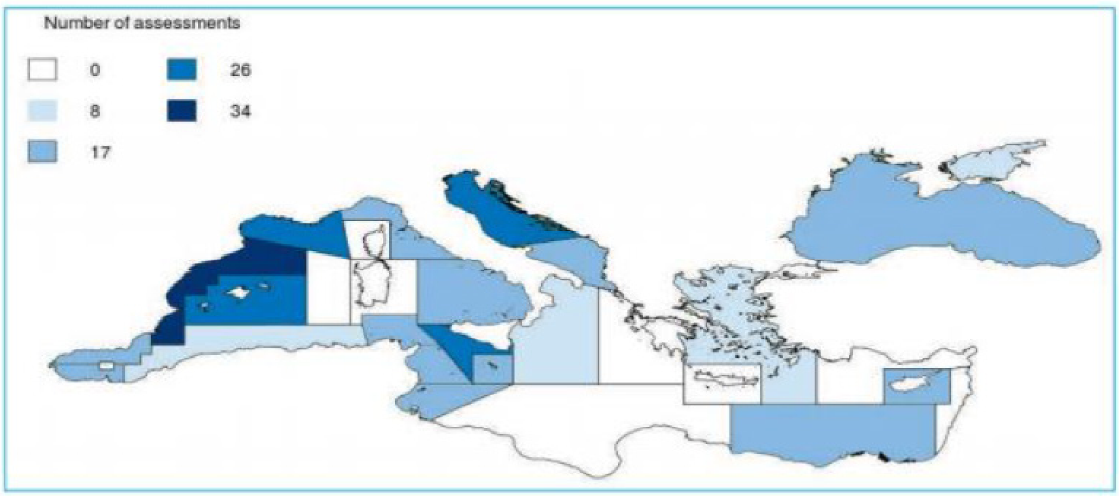


Figure 5: Number of validated assessments for the period 2007-2014 by GSAs (GFCM, 2016-a).

and information needed for performing assessments and formulation of advice (GFCM, 2017-a).

Regional indicators of stock status

In general, the indicator is defined as a data or combination of data collected and processed for a clearly defined analytical or policy purpose (Le Gallic, 2002). More specifically, Miethe *et al.,* (2016) introduced the indicator as a quantity information that can be used as a proxy to describe or relate both stock status (spawning stock biomass, demographic properties or recruitment) and anthropogenic pressure (fishing mortality). Indeed, the indicator makes easy the evaluation of stock status (EC, 2008) and the determination of how the stock is far or close to reach the target values, the reference points, which allow not only in monitoring the sustainability of the fishery sector and the management performance but also in tracking the fishery trajectory in comparison with a planned (target) trajectory (Miethe *et al*., 2016). They can also be developed and reported at various levels of aggregation (Le Gallic, 2002). Therefore, the indicators are a need to describe stock status, to define the pressures affecting the fishery and specially to assess the performance of fisheries policy and management as well as stimulate actions to better pursue sustainability objectives.

Aware about the high importance of developing indicators for exploited populations in achieving its overall objective, since its establishment GFCM makes a considerable effort in this matter. In this regard, the SAC and their technical bodies base the assessment of stock status on a Bi-dimensional approach using both indicators of exploitation intensity (F or/and E) and stock size (TB and SSB). These indicators are routinely computed by its member countries' experts and are annually submitted to the commission through the SAC Working Groups on Stock Assessment where those indicators are confronted with their associated reference points to inform about the health of the commercial stocks (FAO, 2014). The Several indicators used in GFCM assessments and documents are related with (GFCM, 2014-b):

- Yield (MSY, total catch, IUU catches, etc.),
- Fishing pressure and effort (fishing mortality, fishing capacity, etc.),
- Exploited stock abundance (acceptable stock size, safe biological limits, etc.)
- Exploited stock Status (mean body size, minimum landing size, etc.),
- Ecosystem-based approach (MPAs, landings of vulnerable species, composition of the catch, etc.).

However, the GFCM approach was for many years mainly focus on a single species basis (GFCM, 2014-b). Moreover, it was an urgent need for harmonized indicators that could be used both in EU and non-EU members to ensure the minimum requirements of Marine Strategy Framework Directive (MSFD), EcAp process and GFCM fisheries assessment and management objectives. In addition to the need for regional harmonization of methods and data used in the assessment of different descriptors, which will allow in ensuring a coherence amongst the applicable frameworks at regional level with view of avoiding duplication of effort and optimizing the use of resources.

In this regard, GFCM was worked together with UNEP-MAP, mainly within EcAp (Ecosystem Approach) process on the Ecological Objective3 that refers to the "harvest of commercially exploited fish and shellfish populations", one of the 22 ecological objectives that organized in common indicators to assess GES (Good Environmental Status) (CGPM, 2014-b).

As a first result of this work, a technical proposal for the identification of operational objectives, indicators, Good Environmental Status (GES) and targets for Ecological Objective 3 (EO-3) within the UNEP-MAP Ecosystem Approach Process were prepared by the GFCM secretariat. To inform about this EO for commercially exploited populations, three Operational Objectives (OO) have been included. The three OO will serve to assess stock status and health of the stocks as whole as well as the evaluation of the impact of fishing activities on the ecosystem. Thus, these indicators can be applied on the exploited stocks, on the community and on the ecosystem as well (Fig.6) (CGPM, 2014-b).

After being presented to SAC at its 16th session (March 2014) and assessed by GFCM member states, a selected set of indicators of good environmental status of exploited population are considered as common that could be implemented across GFCM area of application, those indicators are: (i) total landing, (ii) fishing mortality, (iii) fishing effort, (iv) spawning biomass and (v) by-catch of vulnerable and non-target species. On the other hand, other indicators were identified as candidate indicators meaning that those will be calculated only after the required data is available. This is due to the fact that such indicators were not commonly assessed in the GFCM context, which require information and some data that is available only in some areas and not regularly submitted to the GFCM (e.g. scientific surveys at sea) (FAO, 2014). However, due to the difficulties related to data collection associated with their use, the candidate indicators are rejected afterwards (GFCM, 2014-b). Then, during the seventeenth session of SAC, it was considered important to link effort and catch by using the catch per unit effort (CPUE) as a more direct indicator of the status of stocks. Consequently, the CPUE was added to the list of common indicators to be used for assessing GES of exploited populations in a relatively straightforward manner across GFCM area of application (FAO, 2015). Therefore, all adopted indicators were incorporated to the final version of the GFCM Data Collection Reference Framework (DCRF), adopted by the SAC (GFCM, 2017-c). In effect, all the approved indicators are in line with Targets 1 and 4 of the Mediterranean and Black Sea Mid-term strategy of GFCM: towards sustainability of Mediterranean Black Sea Fisheries (UNEP-MAP, 2017).

To be applied commonly and at regional scale, the development of a coherent and homogenized methodology is needed. In this regard, the SAC was invited to reflect on the way of aggregate them at the sub-regional and regional scales in order to assess their performance. As a first step, the GFCM secretariat was requested to develop a detailed technical guidance as part of the common indicator guidance factsheets (UNEP-MAP, 2017). As a result, a draft description for the six indicators was prepared and presented to the UNEP/MAP Correspondence Group on Monitoring, Biodiversity and Fisheries (March 2017, Spain). While, the SAC is invited to revise and endorse this description and suggest a roadmap for their estimation at the regional and sub-regional levels (GFCM, 2017-c).

In contrast to the fishing mortality, spawning biomass and total landing indicators that are already used within GFCM approaches and they are regularly computed and submitted to GFCM, the fishing effort, CPUE and BY-CATCH should be further validated in the GFCM-Scientific Advisory Committee on Fisheries (SAC).

Given the high complexity of Mediterranean fisheries, it was proposed during the last session of SAC of GFCM, the use of other important indicators such as the recruitment, body condition and age composition to monitor the status of Mediterranean resources (GFCM, 2017-e; Fig.6).

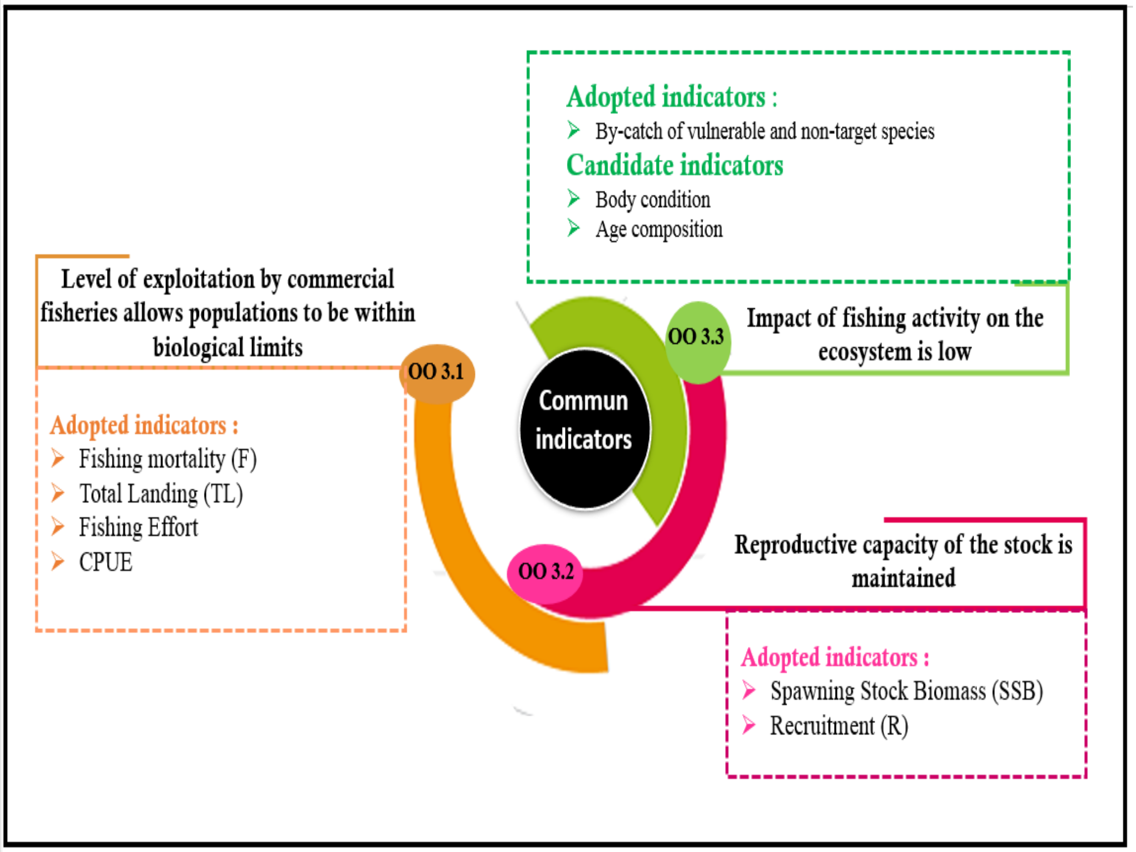


Figure 6: The list of common indicators under the Ecological Objective3 (EO3) adopted to be applied across GFCM area of application (GFCM, 2014 modified). OO: Operational Objective of the EO3 (GFCM, 2017-c and e modified).

1.4. The thesis motivations and objectives

As mentioned in Lleonart (2008), the Mediterranean fisheries state have been reviewed by many authors such as Caddy (1990), Farrugio *et al*., (1993), Farrugio (1996), Anonymous (2001), CIHEAM (2003), Oliver (2003), Lleonart and Maynou (2003), Lleonart (2004, 2005), Bas (2006) and Lleonart (2008, 2015) as well. While, most of them summarized only the current stock status as reported by the competent regional bodies or/and base their analysis on the total annual reported landing.

The state of global fisheries and their trends were widely analyzed by FAO since 1994 through SOFIA editions and also by other authors such as Branch *et al*., (2010). The FAO (2004) explored the global trends in the state of marine fisheries resources for the period 1974-2004 using two different approaches i.e. looking back at the analytical data on the state of exploitation of stock since 1974 and analyzing historical trends in the catch data available at FAO. Furthermore, Branch *et al*., (2010) contrasted the global trends in marine fishery status obtained from catches and from stock assessments to evaluate how use of data affects assessment of fisheries stock status. In contrast, limited studies exist about the trend on the state of Mediterranean fish stocks. Recently, Tsikliras *et al*., (2013) examined the exploitation trends of the Mediterranean and Black Sea fisheries using the total annual catches, the variability of the mean trophic level of the catch and fishing-in-balance index for the period 1970-2010. To explore the Mediterranean fisheries status Tsikliras *et al.,* (2013) was classified the total catches into exploitation categories according to the catch-based method of stock classification, and it was revealed that the Mediterranean and Black Sea fisheries are exploited unsustainably. Vasilakopoulos *et al*., (2014) investigate the aggregate temporal trends of 42 Mediterranean stocks in 1990–2010 to reveal a steady deterioration of the exploitation regimes (exploitation rate and selectivity) and SSB, they found that the current selectivity is far from optimal, especially for demersal stocks. Recently, GFCM (FAO, 2016-a) reviewed the state of the exploitation of assessed fish stocks belonging within its area of application basing on the indicator of fishing mortality in relation to their associated reference point (F_{MSY} or its proxy). It was revealed that up to 85% of Mediterranean and Black Sea stocks assessed are fished at biologically unsustainable level. More recently, Cardinale and Scarcella (2017) analyzed all available stock assessment and effort data for the most important commercial species and fleets in the Mediterranean Sea since 2003 and they found that there is no apparent relationship between nominal effort and fishing mortality for all species. Also, it was shown that the fishing mortality has remained stable during the last decade, for most species, with a significant decline observed only for red mullet and giant red shrimp but an increase for sardine stocks.

Context and importance of this study

This study falls under the umbrella of the International Master's Program in Sustainable Fisheries Management. Its constitutes its second part that is devoted to a period of initiation to research or to professional activity in which participants work on their Final Master Project. In effect, this master is jointly organized by the University of Alicante

(UA) and the Ministry of Agriculture and Fisheries, Food and Environment through the International Center for Advanced Agricultural Studies CIHEAM / IAMZ with the collaboration of FAO-GFCM. Within the framework of this collaboration, this extern internship as well as the present master thesis are effectuated in GFCM headquarter in Rome-Italy for a period of 10 months under the direct supervision of Mr. Miguel Bernal.

Recently the issue of the state of Mediterranean stocks has been treated by several authors, while quasi-all the performed studies mainly relies on the harvest intensity to inform about the stock status. However, exploring what is occurring in the stock as a response to the applied harvest intensity, especially pointing out how the stock reproductive capacity (SSB) and the recruitment are affected by the fishing mortality are of crucial relevance for an accurate diagnosis of stock status. Moreover, the assessment of the temporal trend in indicator of stock size and exploitation intensity determine if the stock status is improving or worsening. Therefore, a study based on a simultaneous analysis of both indicators of exploitation and stock size as well as their temporal trend remain a need to provide a clearer diagnostic of stock status and to point out what occur especially inside the stock size with respect to the applied level of fishing mortality.

In effect, the SAC of GFCM assesses the Mediterranean stocks annually and the results are stored in GFCM stock assessment database, however, the result analysis is conducted at stock level. In addition, it was revealed that some assessments are presented to STECF and not submitted to GFCM, meaning that such as stocks are not included in assessing the status of Mediterranean stocks, which limit the geographical coverage of advice on the use of Mediterranean living marine resources. In this regard, a devoted study to compile on one hand all the relevant data on stock assessment presented and endorsed by Mediterranean Regional Management Organizations such as the STECF of EC and SAC of GFCM and to carry out an overall analysis of Mediterranean stock status as well as their trends at regional level on the other hand is a need.

In this context, the present study aims to carry out a spatio-temporal analysis of Mediterranean stock status using the most reliable data and covering the maximum possible of GSAs and time series. To advance towards the overall objective some specific goals are defined as follows:

- Compile all relevant data on stock assessment, especially the validated assessments by SAC of GFCM and STECF of EC.
- Update GFCM stock assessment database by conducting checks, corrections and completeness of GFCM library metadata as well as digitalizing Stock Assessment Forms (SAFs) in view to incorporate them in the database.
- Contribute in improving SAFs and GFCM database through providing some relevant recommendations to fill gaps and improve the detected limitations.
- Carry out an overall analysis of Mediterranean current stock status based on the most reliable available data intending covering the maximum number of stocks and GSAs.
- Explore Mediterranean stock status at different levels; at stock level as well as at sub-regional and regional scale.
- Aggregate the indicators at regional level with view to explore the temporal trend of Mediterranean stock status at whole.

- Conduct a deeper analysis applied to selected stocks to provide a case study of stock-by-stock approach.
- Offer propositions, ideas and recommendations that would contribute to improve the stock status analysis, to redress the current Mediterranean stock status and to reverse their trend.

Moreover, this study expects:

- ✓ Provide GFCM users with an updated database.
- ✓ Contribute in improving the GFCM stock assessment database.
- ✓ Provide an up-to-date diagnosis of the Mediterranean stock status basing on the most reliable data and covering the maximum possible of GSAs
- ✓ Provide an application of common indicators (Fishing mortality and spawning Stock biomass) aggregated at regional and sub-regional scale.
- ✓ Contribute in enhancing knowledge and information on stock assessment in the GFCM area of application, in line with the Target 1 of GFCM Mid-term strategy (2017-2020).
- ✓ Contribute in the next publication of the State of Mediterranean and Black Sea Fisheries (SoMFi- 2018).

The document structure

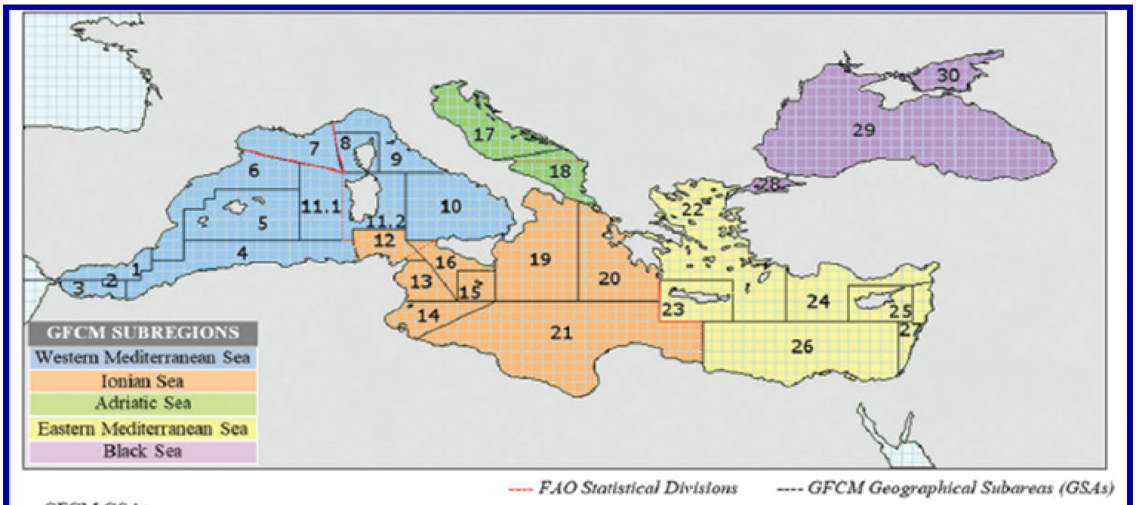
To make the present paper harmonious and coherent, it was organized in five main chapters. The first one provides a general introduction, which includes (i) an overview on the Mediterranean and Black Sea marine resources and fisheries, (ii) a summary on the Mediterranean fisheries management and (iii) an introduction to GFCM work pointing out both the process of providing advice within GFCM approach and stock assessments carried out in its area of application as well as (iv) the present study motivations and objectives. The second chapter reports the data used and describes in detail the methodologies followed and approaches adopted to get the study results. The obtained results are provided in chapter three and discussed in chapter four. In effect, to make the study results organized, it was considered logic dedicate a first part to explore the contribution of the included species in this analysis to the landing of Mediterranean sub-regions. Then, the analysis of Mediterranean stock status was organized in three main parts. The first one provides an overall analysis of the current stock status, which it itself divided into three sub-parts exploring the status at different level, namely at regional, at species and at sub-regional scale, using the sub-regions as defined in the DCRF (GFCM, 2017-a). The second part is devoted to explore the temporal trend on stocks status. While, the third part contains a case study that focuses on the state of two selected fisheries starting by a comparative analysis of the outcomes of last successive assessments as well as a comparison between indicator time series from last validated assessment and that built from the annual reported current indicator value. The last chapter summaries the salient conclusions and proposes some recommendations that would improve the state of Mediterranean commercial stocks and contribute in insuring the sustainability of living marine resources for the future generations.

2. Material and methods

2.1. Study area presentation.

The study area is corresponding to GFCM area of application (FAO major fishing area 37), especially, the Mediterranean Sea at whole from the Straits of Gibraltar to Bosphorus, which englobes 27 Geographical Sub-Areas (GSAs).

The Mediterranean GSAs were aggregated by GFCM into four sub-regions, namely; (i) the Western, (ii) Central and (iii) Eastern Mediterranean as well as (iv) the Adriatic Sea. The Western Mediterranean encompasses GSAs 1 to 11, the GSAs 12 to 21 form the Central Mediterranean and the Eastern Mediterranean involves GSAs 22-27. While, the Adriatic Sea encompasses GSAs 17-18 (GFCM, 2016-b) (Fig.7).



GFCM GSAs

01 - Northern Alboran Sea	07 - Gulf of Lion	13 - Gulf of Hammamet	19 - Western Ionian Sea	25 - Cyprus
02 - Alboran Island	08 - Corsica	14 - Gulf of Gabes	20 - Eastern Ionian Sea	26 - South Levant Sea
03 - Southern Alboran Sea	09 - Ligurian Sea and Northern Tyrrhenian Sea	15 - Malta	21 - Southern Ionian Sea	27 - Eastern Levant Sea
04 - Algeria	10 - South and Central Tyrrhenian Sea	16 - Southern Sicily	22 - Aegean Sea	28 - Marmara Sea
05 - Balearic Islands	11.1 - Sardinia (west) 11.2 - Sardinia (east)	17 - Northern Adriatic Sea	23 - Crete	29 - Black Sea
06 - Northern Spain	12 - Northern Tunisia	18 - Southern Adriatic Sea	24 - North Levant Sea	30 - Azov Sea

Figure 7:Localization of the study area (the Mediterranean Sea from GSA 1 to GSA 27) (FAO, 2016-a).

This study not only provided the analysis of Mediterranean stock status by stocks (GSAs) and by GFCM sub-regions but it also focused the analysis on specific fisheries, notably the small pelagic (sardine and anchovy) in the Adriatic Sea and the hake and Deep-water rose shrimp in the Strait of Sicily. Those fisheries were selected thanks to their high importance in terms of fishing activity, including biodiversity, production and economic value. Further, the selected fisheries are under the GFCM multi-annual management plans.

❋ Overview on the Strait of Sicily

The strait of Sicily covers a great part of the Central Mediterranean being bounded by the Sicily Island to the north, by the Tunisia-Sardinia Channel to the west, by Tunisia coasts to the south-west, Libyan coast to the south and Ionian Sea to the east (UNEP-MAP, 2015). It is divided into 5 Geographical sub-areas, mainly GSA 12, 13, 14 that represent the Tunisian side, GSA 15 represents Maltese water and GSA 16 which corresponding to Sicilian marine Waters (Fig.8).

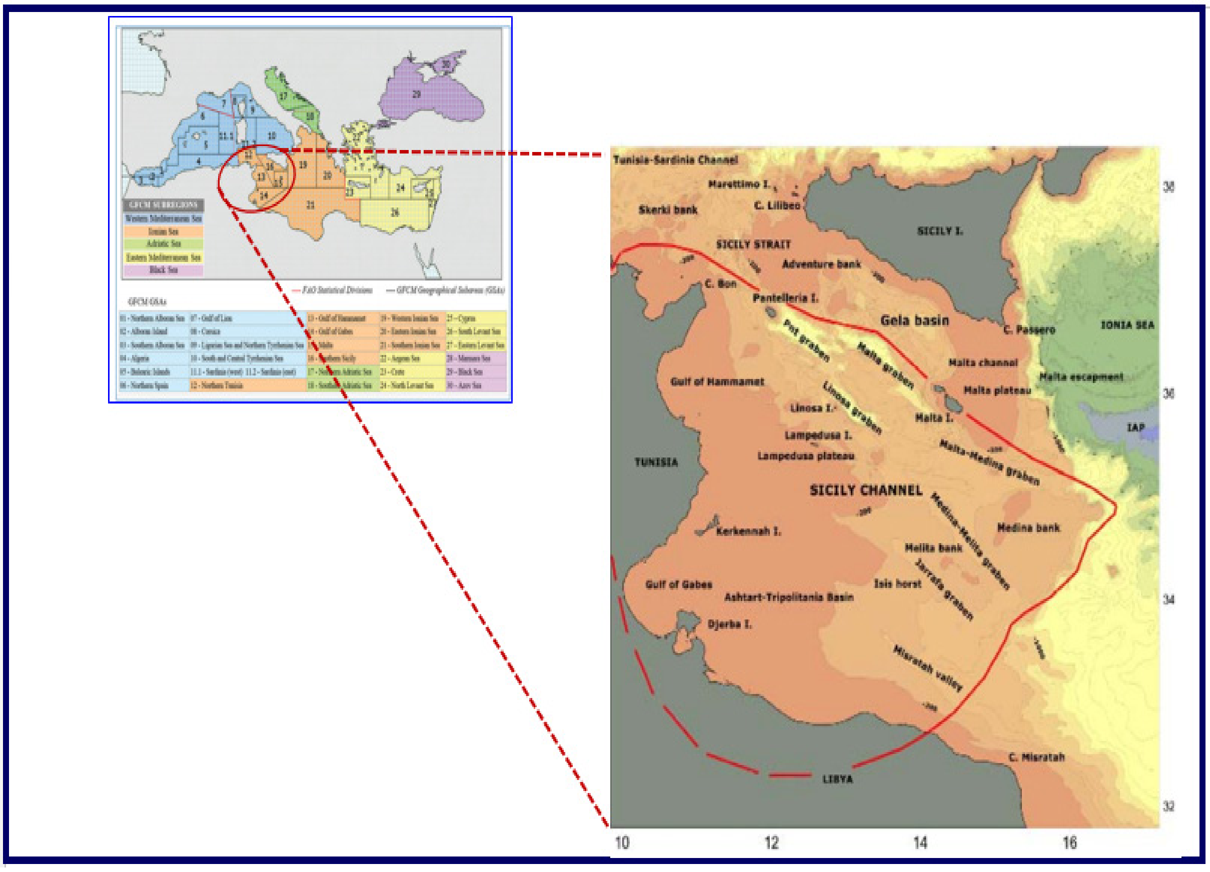


Figure 8: localization of the Strait of Sicily within the Mediterranean Sea. (UNEP/MAP, 2015 modified).

The Strait of Sicily is considered one of the most important Mediterranean fishing area known as a productive zone where a significate fleets operate (Farrugio & Soldo, 2014-a).

The Strait of Sicily is characterized by a particular topography and hydrology, i.e. special bottom structure and high important hydrodynamic process. In fact, along the southern part of Sicily, the shelf is characterized by two wide and shallow banks in the western and in eastern sectors, the Adventure Bank and the Malta Bank, respectively (Fig.9). Furthermore, a large shallow shelf characterizes the area on the south close to Tunisia and Libya. The complex circulation patterns together with bottom structures (i.e., seamounts, banks, volcanoes, pockmarks and steep walled basins) are the main features behind the Sicily Channel biodiversity richness, where several important commercial species find favorable habitat, spawning and nursery areas such as anchovies, Bluefin tuna, European hake and Deep water Deep-water rose shrimp (UNEP/MAP, 2015).

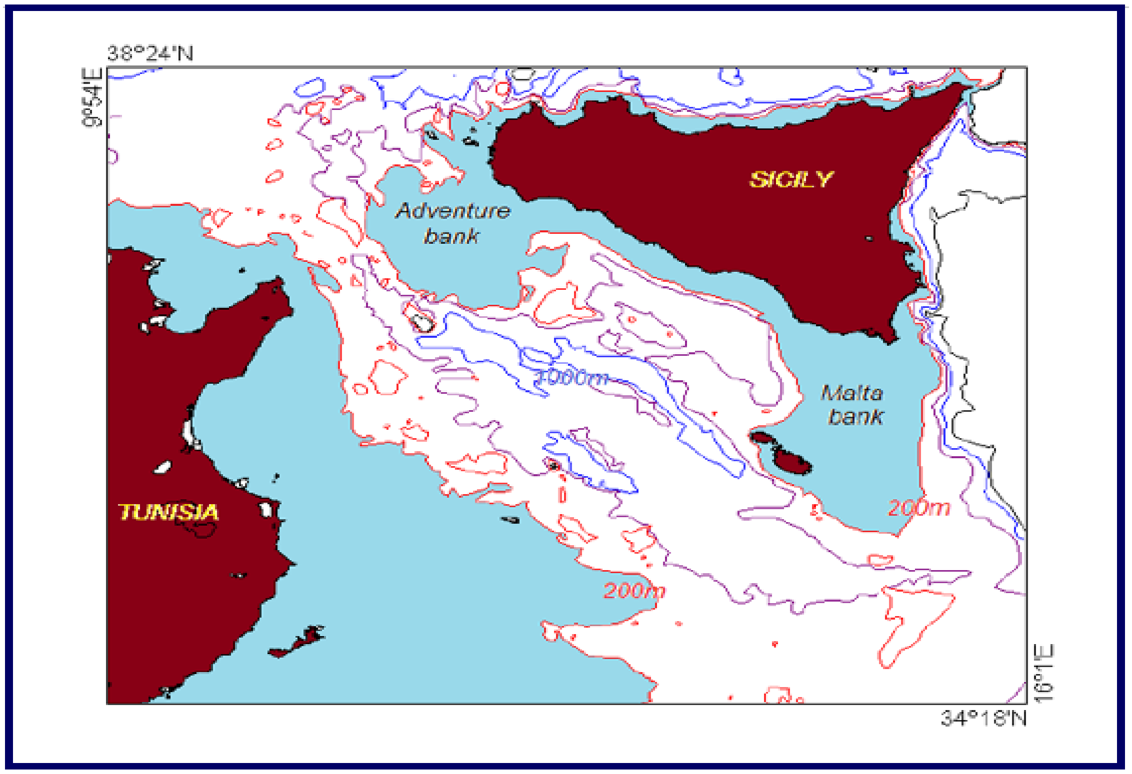


Figure 9: Map of the bathymetry and topography of Strait of Sicily (source: Farrugio & Soldo, 2014-a).

- **Overview on the Adriatic Sea.**

The Adriatic Sea is a semi-enclosed basin characterized by the largest shelf area of the Mediterranean extending over its Northern and Central parts and where the bottom depth does not exceed 100 m, except in the Pomo/Jabuka Pit area where the depth is about 200-260 m (Fig.10).

This sea is connected to the rest of the Mediterranean through the Channel of Otranto in the south, which is the narrowest part of the basin where the depth is about 1223 m (Fig. 10). The Adriatic Sea is supplied with Eastern Mediterranean water via Channel of Otranto and with fresh water runoff from Italian rivers producing, hence, a seasonality in latitudinal and longitudinal gradients in hydrographic characteristics along the basin. Moreover, its bottom sediments are very diverse where all types can be found (FAO AdriaMed, 2004-a; Farrugio & Soldo, 2014-b).

The Adriatic Sea is bordered by six coastal states in total (Albania, Bosnia and Herzegovina, Croatia, Italy, Slovenia and Montenegro). For management purpose, the basin was divided into two Geographical sub-areas, namely GSA 17 and GSA 18. The first one encompasses Italy, Croatia, Bosnia-Herzegovinian and Slovenia, while

Albania, Italy and Montenegro are included in GSA 18 (Farrugio & Soldo, 2014-b; FAO, 2016-a; Fig. 10).

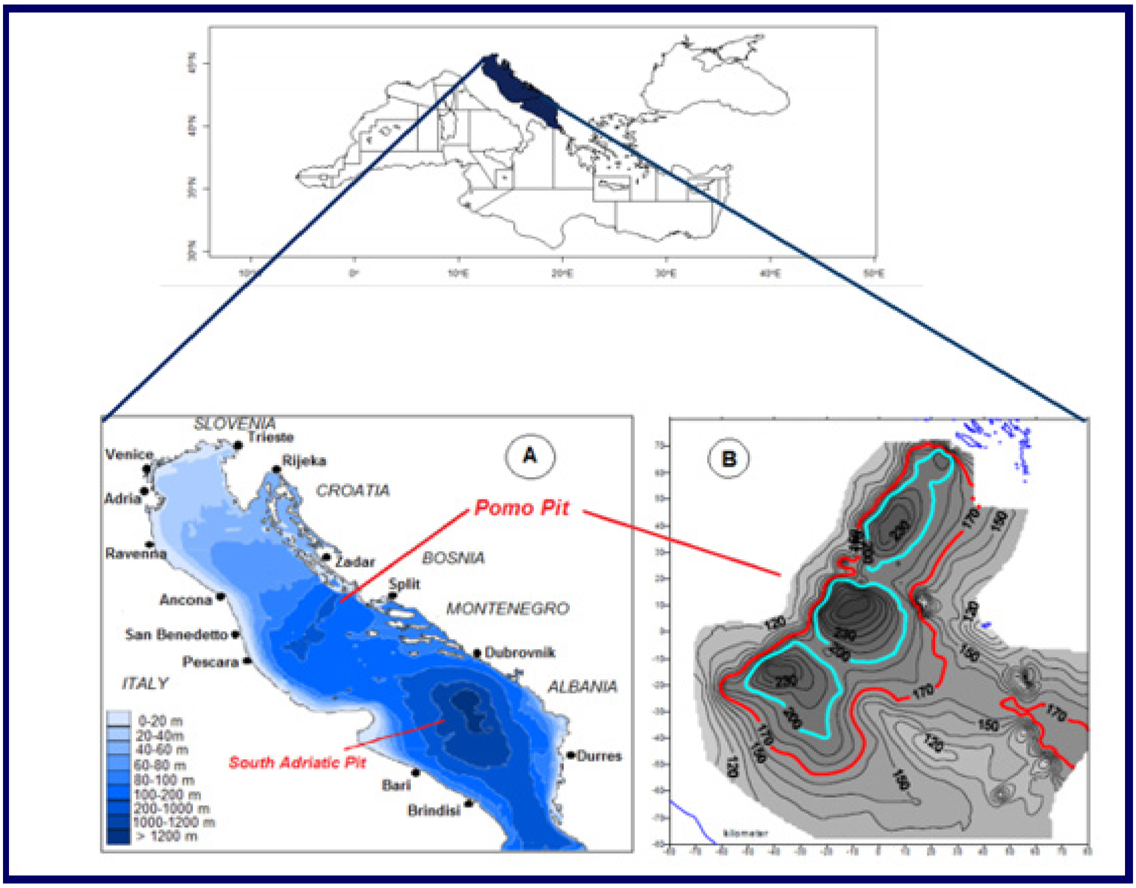


Figure 10: Bathymetry of the Adriatic Sea (A) with zoom on the Pomo Jubko Pit area (B) (source: Farrugio & Soldo, 2014-b *modified).*

2.2. Data used

2.2.1. Sources of data

Aware about the importance of basing the study results on a reliable data, a considerable time was allocated to data collection, checking and preparation. Indeed, to compile as diverse and updated data as possible several sources were consulted (Fig.11). Among them, GFCM online system (SharePoint), GFCM website (http://www.fao.org/gfcm), GFCM capture production online database and Scientific, Technical and Economic Committee for Fisheries (STECF) website (https://stecf.jrc.ec.europa.eu).

GFCM database

GFCM *SharePoint*, mainly the library of SAFs, constitutes the main source of data for the present study. This database is an online system that incorporates Stock Assessment Forms (SAFs), Metadata (stock status indicators (F, SSB, R, and TL), Bi-dimensional Stock status (BSS) / Reference points…), scripts and raw data. All stock assessments performed within GFCM area of application from 2007 onwards are collected and stored in this library through the SAFs. In addition, SharePoint stores and provides its users with final reports and presentations resulted from GFCM events (meetings, workshops, trainings….). GFCM allowed the access to this online system and hence it was discovered and exploited in favor of this study.

The SAF is a word template, approved during the fifteenth session of the SAC, that summarizes the stock assessment carried out during the annual meeting of the Working Groups on Stock Assessment (WGSAD/WGSASP) of Scientific Advisory Committee on Fisheries of GFCM. Through the SAFs, the GFCM member states submit data on fisheries including fishing gear, a short description of the fleet, historical trends on catches, and biological parameters of growth and maturity, as well as a the set of reference points used and results obtained (i.e. F, SSB etc.). The SAFs served to obtain information on the stock assessment methods used within the study area and to compile the indicators of stock status as well as the set of established reference points.

Furthermore, through SharePoint the GFCM expert groups home was accessed and their reports and presentations were consulted to aliment and enhance the study data. The main consulted expert groups are the SAC Working Groups on Stock Assessments and the SAC Regional Sub-Committees, namely that for the Western Mediterranean (RSC-WM), for the Central Mediterranean (SC-WM), for the Adriatic Sea (RSC-AS) and for the Eastern Mediterranean (RSC-EM).

The STECF annual reports on stock assessments

To cover more GSAs and include more assessments in the present study, the reports referring to the assessments of Mediterranean and Black Sea stocks conducted by the STECF were uploaded from their Website. From these reports, indicator based assessments (Fishing mortality and stock size estimates) and their corresponding reference points are extracted and used in the analysis.

GFCM meetings and events

To fill in many gaps in indicator time series and reference points reported in SAFs, attempting to the GFCM meetings and events linked to the study topic was given a particular importance. During the period of working on this topic, two relevant events were occurred in GFCM which served as important sources of data. The first one is the Working Group on Stock Assessment of Demersal species (WGSAD) and of small Pelagic species (WGSAP) meeting and the second one is the SAC Regional Sub-Committees meeting. Those events were an opportunity to (i) attend to the assessment of Mediterranean stocks, (ii) to compile Stock Assessment Forms (SAFs) and (iii) to complete with GFCM national experts the missing data in the previous reported SAFs.

GFCM capture production database.

The Mediterranean reported annual landings were extracted from GFCM capture production database. From this online system, the landings are aggregated by group of species and by sub-regions. In this online database, the species are aggregated in accordance with FAO International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP):

To concentrate the analysis on the fish (excluding the high migratory species) and shellfish marine Mediterranean production, as is the goal of this work, the followings ISSCAAP groups are excluded from the present analysis:

- Carp, barbel and other cyprinids;
- Miscellaneous freshwater fish;
- Tuna, bonito, billfish;
- Freshwater crustaceans;
- Brown seaweeds;
- Red seaweeds;
- Miscellaneous aquatic plants

Other sources

To collect some missing data in SAFs and to bridge gaps in indicator time series, an official E-mail was prepared to contact GFCM national experts. Furthermore, GFCM Data collection Reference Framework (DCRF) and GFCM Mid-term strategy (2017-2020) were used to inform about the GFCM priority species and shared stocks. In addition, the GFCM website are consulted to make out the GFCM Geographical Sub-Areas (GSAs) delimitation and aggregations into sub-regions such as the Western, the Central and the Eastern Mediterranean as well as the Adriatic Sea.

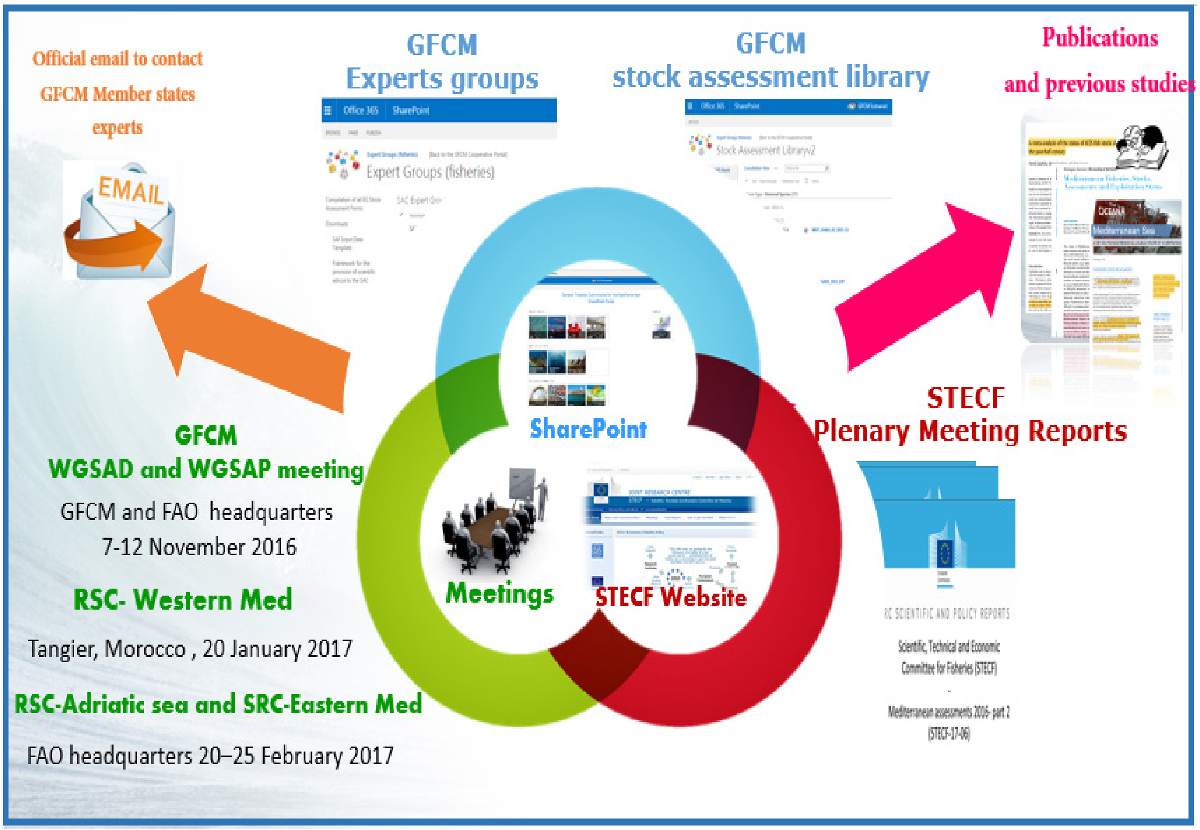


Figure 11: Study data sources

2.2.2. Data collected

From the several sources of data cited above, a set of data was collected and summarized according to their source in the Tab.1.

To base this study results on a the most reliable data, only the validated assessments by SAC of GFCM or STECF of EC are considered in the study. Moreover, giving that they constitute the main source of data of the present study, a great important was given to check all SAFs of validated assessments. To ensure that the key information of stock assessment (data, method, results and final advice) are correctly extracted from SAFs to the library metadata, the SAFs library metadata (SharePoint) is reviewed and updated.

Table 1:Summary on collected data

Data source	Kind of Data	The available data and the covered time period
Stock Assessment Forms (SAFs)[1]	Fishery information: fleet segment, catch and/or landing, historical trends, management regulations and reference points Fishery independent information: description of the direct method used and spatial distribution of the resource, Biological information: Natural mortality vector and Growth parameters Stock assessment: input data and parameters, tuning data, results (Fishing mortality(F), Recruitment (R), Spawning Stock Biomass(SSB) and Total Biomass (TB)) Stock predictions Final scientific advice	Available for both small pelagic and demersal species from 2007 to 2015 (reference years)
GFCM stock assessment library metadata[2]	Fishing mortality (F) Current Recruitment (R) Current Stock Spawning Biomass(SSB) Current Total Biomass (TB) Bi-dimensional Stock Status (BSS)	Available by area and by species (both small pelagic and demersal species) from 2007 to 2015
Stock assessment Output excel file[3]	An Excel template file was prepared by GFCM secretariat and circulated with the experts to store the assessment outputs in terms of time series of F, SSB, R and TB.	Only exist for stock assessments run for the reference year 2015 (reported in 2016)

[1] https://gfcm.sharepoint.com/EG/Stock%20Assessment%20Libraryv2/Forms/Consultation%20View.aspx?viewpath=%2FEG%2FStock%20Assessment%20Libraryv2%2FForms%2FConsultation%20View.aspx

[2] http://www.fao.org/gfcm/reports/en/\

[3] https://gfcm.sharepoint.com/EG/SitePages/WGSAD_Yr_.aspx?RefYear=2016#

WGSASP, WGSADS and SAC reports available in SharePoint and in GFCM website	-Summaries on stock assessment (models used, natural mortality estimation methods, stocks assessed per year, reference points and stock status) -The most appropriate natural mortality (M) vector/ model by stock and GSA (identified by the working group) -Working group recommendations, comments and scientific advice by stock and by GSA -Assessment analysis -Overview on the Mediterranean stock status at whole	WGSASP, WGSADS reports: available from 2012 to 2015 SAC reports: available from 2002 to 2015
STECF reports of assessment of Mediterranean and Black Sea stocks [4]	Indicators of stock status Reference points Information about the Mediterranean fisheries	Available for both small pelagic and demersal species from 2007 onwards (reference years)
GFCM capture production database.	Indicator of Total Landing.	Available by species groups and by GFCM sub-regions over the period 1970-2014.
GFCM Data collection Reference Framework (DCRF)	Priority species Shared stocks GFCM sub-regions	---

2.3. Software used

To make the collected data analyzable, it was first explored and then cleaned, transformed and modeled and visualized with the goal of discovering useful information, suggesting conclusions, and supporting decision-making. Excel 2013 as well as the software R Studio, version 3.3.1 were used in the present study. The package "ggplot 2" was run to plot the temporal trend in F/F_{MSY}, B/B_{PA} and R/mean R. Moreover, R studio was used to compute the regression equation, R squared and the p-value. The boxplot function was applied to plot the set of indicator values on boxplot.

2.4. Methodology

2.4.1. Indicators of stock status

As outlined in chapter 1, the "indicators" are required to monitor the status of the fishery relative to the chosen "reference points". Many indicators exist, however, due to the constraint of availability of a regularly data allowing to build an analyzable time series and taking into account the final list of common indicators adopted by GFCM to

[4] https://stecf.jrc.ec.europa.eu/reports/medbs

be applied through its area of application, the set of main indicators adopted to assess current status of Mediterranean stocks as well as their temporal trend are as follows:

(i) Spawning Stock Biomass (SSB),
(ii) Recruitment (R)
(iii) Fishing mortality (F) and/or Exploitation rate (E),
(iv) Total Landing (TL).

The indicator based assessments (SSB, R, F and E) are estimated as a regularly basis and submitted to GFCM trough the SAFs. The annual total landings are uploaded from GFCM capture production online database.

Recruitment (R) (to the area) refers to the total number of individuals of a stock that enter the fishery area for the first time each year (9). This indicator was adopted given its great importance in analyzing the exploitation effect on the future generation and in view of its ability in detecting the “Recruitment overfishing".

Spawning Stock Biomass (SSB) refers to the total weight (biomass) of the spawning stock, which has already spawned at least once (8). It reflects the reproductive stock capacity (GFCM, 2017-c**)**. Moreover, the assessment of the state of this indicator in relation to the reference points help in detecting the “recruitment overfishing”, if it exists.

As it is stated by FAO (9), the growth overfishing is a kind of overfishing occurring when the young fish that become available to the fishery (the “recruits”) are caught before they can grow to a reasonable size. However, the recruitment overfishing is what occurs when the parental biomass is reduced by fishing, which results in producing a not enough young fish quantity necessary to keep the stock self-renewable capacity. It is characterized by a decreasing proportion of older fish in the catch as well as a great reduction of spawning stock biomass (9) and recruitment.

To assess the status of fishing pressure applied to assessed stocks, *F* was considered for demersal species, while *E* (F/Z) was adopted to assess the majority of small pelagic. The ratio F/Z was used because it allows obtaining more comparable indices across pelagic stocks and across years. In addition, the F/Z was considered more reliable indicator of fishing mortality applied to small pelagic stocks, because it takes into consideration the change of the natural mortality in different species and even within stocks of the same species, plus it is widely used within GFCM working group on stock assessment (GFCM, 2016-a).

F is the instantaneous rate of the mortality of the number of individuals that die due to fishing (GFCM, 2017-c). While, E (F/Z) refers to the proportion of a population that is caught during a certain period, usually a year. F (fishing mortality) and M (natural mortality) together make up the total mortality rate Z. With M being the instantaneous exponential rate at which fish in the population die from natural causes (FAO, 2006-b).

Total Landing (TL) is the total amount of fish landed and officially registered. While, the total catch corresponds to the total amount of fish taken by the fishing gear, which reaches the deck of the fishing vessel, including the discards (GFCM, 2017-c).

Therefore, the total catch reflects better the quantity of fish caught by the fishing gear. However, due to unavailability of such data for all studied area, the total landing was used as a proxy to total catches, in line with GFCM, 2017-c. This indicator is used to measure the exploitation trend and to point out the landing composition at each GFCM sub-region.

From the indicator based-stock-assessment (SSB, F and R) and using their associated reference points, the exploitation (F/F_{MSY}) and biomass ratios (B/B_{PA}) as well as the recruitment index (R/mean R) were estimated and used to assess the stock status. These indicators measure how far or near is the examined stock from its target level, i.e. the associated reference point (Tab.2).

Moreover, the percentage of the number of stocks assessed as (i) inside, (ii) at and (iii) outside safe biological limits as well as the proportion of stocks above and below the F_{MSY} level were used to assess the stock status at regional, sub-regional and group of species level (Tab.2).

2.4.2. Reference points

FAO (1997 and glossary) and Fletcher *et al*., (2002) define a fishery reference point as "*a benchmark against which to assess the performance of management in achieving an operational objective*". The reference points are crucial elements for assessing stock status and provision advice for fisheries management, and their role was defined in the GFCM Guidelines for management plans, approved at the 36th session of the Commission (GFCM, 2014-b). In general, the reference points serve to compare the current value of estimated indicators with the target ones, which allows quantify how far or near the estimated indicator from the desirable situation. Three types of reference points exist, notably target, limit and threshold reference points.

Among others, Caddy and Mahon (1995) defined the Target Reference Point (TRP) as "*the level of fishing mortality or of biomass, which permit a long-term sustainable exploitation of the stocks, with the best possible catch*". It is also known as a management reference point that quantify the desirable situation of the stock (FAO, 2014). However, the Limit Reference Points, LRP, are maximum values of the fishing mortality (F_{LIM}) or minimum values of the biomass (B_{LIM} or B_{LOSS}), which must not be exceeded. Otherwise, the stock self-renewal capacity might be endangered.

To reduce the probability in exceeding the LRP, a precautionary reference points (threshold reference point) are needed either as fishing mortality or biomass. As they introduced by FAO (2014), these reference points serve as a red flag and may trigger particular management actions designed to reduce the fishing mortality. Moreover, as pointed out by Caddy and Mahon (1995), the uncertainties associated with the estimation of limit reference points require the use of a precautionary reference point, mainly F_{PA} and B_{PA}. So, by precaution, the scientific advice should be based on biomass and fishing mortality reference point limits (B_{LIM} and F_{LIM}), thresholds (B_{PA} and F_{PA}) and targets (B_{TARGET} and F_{TARGET}) (FAO, 2014).

The fishing mortality reference points used within GFCM area of application are $F_{0,1}$ and/or F_{MSY} when analytical assessments allowed for their estimation. If not, the empirical Patterson's reference point ($E_{Patterson} = 0.4$) for exploitation rate is used, particularly used to assess small pelagic stocks. Hence, these reference points are used in this study to assess the exploitation status.

$E_{\text{"patterson"}}$, is an empirical reference point suggested by Patterson (1992) as a possible biological reference point for the management of small pelagic, which can be used when no analytical reference points are available.

F_{MSY} introduced by GFCM (2017-c) as the value of F expected to produce the long-term maximum sustainable yield. This reference point is considered by the commission as limit reference point due to the consequences of overestimating F (GFCM, 2017-c). While, $F_{0.1}$ is defined as the fishing mortality at which the slope of the Yield per Recruit (YPR) curve is 10 percent of its slope at the origin (FAO, 2006-b; FAO, 2014). As pointed out during the sixteenth session of SAC (FAO, 2014), when fishing mortality is used as an indicator, $F_{0.1}$ can be used as a proxy for $F_{MSY.}$

To assess the biomass status, the analytical reference points, namely B_{MSY} is used when data allowing to estimate it. Otherwise, B_{LIM} and $B_{THRESHOLD}$, which are based on empirical analysis of biomass estimates time series, are used as agreed at the WGSAD meeting in 2012 and as collected through the SAF template.

B_{LOSS} is used as a proxy for B_{LIM}. B_{LOSS} being defined as the lowest biomass from which a recovery has been confirmed. It is estimated from an analysis of biomass estimates time series (GFCM, 2016-a). From B_{LIM}, an estimate of B_{PA} (Biomass reference point according to the precautionary approach) could be obtained (GFCM, 2016-b). B_{PA} (Biomass threshold) is defined as a point at which the probability to be below B_{LIM} (Biomass limit) is lower than 5%. In absence of precise estimates of the distribution of the biomass estimate, a log normal distribution of B_{LIM} should be assumed, with a coefficient of variation of 40% (GFCM, 2017-c). This approximately results in $B_{PA} = 2 * B_{LIM}$ (GFCM, 2016-a). Therefore, when it is available in SAFs or other published reports of SAC or STECF, the B_{PA} was used to assess the biomass status of stocks examined in the present study. If only the B_{LIM} is established, the formula ($B_{PA} = 2 * B_{LIM}$) was used to get the Biomass threshold reference point. However, except the small pelagic stocks, limit and threshold biomass reference points are not estimated for the most demersal Mediterranean assessed stocks. On the other hand, the biomass status of those stocks is assessed by SAC Working Group on Stock Assessment of Demersal species (WGSAD) using the percentiles of biomass estimated from the time series of total biomass (TB) or spawning biomass (SSB) resulted from the stock assessment model (GFCM, 2016-b). Those biomass percentiles are notably the 33^{rd} and the 66^{th}, which for the purposes of this thesis are used as a proxy of B_{LIM} and B_{PA}, respectively.

To fill in these gaps and work in a coherent manner, in this paper the B_{PA} was adopted to assess the stock biomass of all included stocks in the present study. The B_{PA} equal to two times B_{LIM} is used as the biomass threshold reference point for monitor the status of small pelagic biomass. However, the 66^{th} percentile of biomass is adopted to assess the status of demersal stock size.

Table 2: Indicator of stock status used in this study and the corresponding assessed criteria.

The assessed criteria	Indicator	The reference level	Coverage	
			Spatial	Temporal
Exploitation status	1- current fishing mortality (F) value 2- temporal trend in exploitation ratio (F/F_{MSY})	1) - F_{MSY} or its proxy 2) - Decreasing or increasing temporal trend of exploitation ratio with relative level $F/F_{MSY} = 1$ using linear regression and percentage of change.	At regional, sub-regional and stock level.	1-The most recent available validated assessment carried out with reference year from 2009 onwards 2-1975-2015
	Total Landing trend	Decreasing or increasing trend using linear regression and percentage of change.	Regional and sub-regional	1970-2014
Status of stock reproductive capacity (or stock size)	1- Current Spawning Stock Biomass (SSB) 2- Temporal trend in relative biomass (SSB/SSB_{PA} (or its proxy))	1)- SSB_{PA} or its proxy (66^{th} percentile of SSB) 2)- decreasing or increasing trend with relative level $SSB/SSB_{PA} = 1$	At regional, sub-regional and stock level.	1- The most recent available validated assessment carried out with reference year from 2009 onwards 2-1980-2015
Juveniles status	Temporal trend of recruitment index (R/mean R)	R/mean R is below or above 1	Regional	1- the most recent available validated assessment 2-1980-2015
Current regional and sub-regional stock status	Proportion (%) of stocks below, at and outside safe biological limits	Percentage is below or above 50 %.	At regional and sub-regional level.	The most recent available validated assessment carried out with reference
	Proportion (%) of stocks above and those below F/F_{MSY}			
	Proportion (%) of			

	stock above and those below B/B_{PA}			year from 2009 onwards
	Proportion (%) of stocks (i) in overfishing ($F>F_{MSY}$), (ii) those overfished ($B<B_{Ref.\ point}$), (iii) in overfishing and overfished and (iv) those neither overfished nor in overfishing			
Assessed stocks regional (or regional) coverage	The Proportion (%) of assessed landing from total sub-regional (or regional) reported landing.	Percentage is below or above 50 %.	At sub-regional level.	The most recent available validated assessment carried out with reference year from 2009 onwards

2.4.3. Definition of the stock status

Generally, stock status is determined by estimating current levels of fishing mortality and spawning-stock biomass (or Total biomass) and comparing these with reference points, which are typically associated with maximum sustainable yield (MSY) (Brooks *et al.*, 2010).

The definition of Mediterranean stock status within GFCM approach is based on both stock abundance and on exploitation rate status, i.e., *Bidimentional stock status* (BSS). The BSS stock status are particularly described based on the values of estimated indicators (Total Biomass and/or Spawning Stock Biomass as an abundance indicator and Finishing mortality as an exploitation rate indicator) against their associated reference points, mainly exploitation and biomass reference points.

2.4.4. Analysis of Mediterranean current stock status

In this study, the analysis was performed using two different approaches, but complementary with each other, notably (i) a single stock analysis (stock-by-stock approach) applied to selected stocks and (ii) a meta-analysis of the Mediterranean stocks.

The meta-analysis is defined as a statistical process that combines large collection of results from previous similar studies, converts them to a common metric and combines them to obtain an average effect size as well as determining the overall effect with the purpose of integrating their respective findings (Glauss (1976); the Joanna Briggs Institute (2014))

The meta-analysis is a valuable tool to synthesize the results of individual stock assessment results and to make the general trend patterns clearer than when looking at development within individual stocks. This method can be used to point out the maximum sustainable yield (MSY) and identify the recruitment overfishing at meta-scale (Sparholt *et al.,* 2007)

However, the meta-analysis hides important stock specific features such as the potential for some stock to tolerate greater exploitation level and makes difficult identifying the stocks for which the status is ameliorated from those for which their status became worse. Moreover, performing a stock-by-stock analysis illustrates the stock specific conditions, problems and historic and then suggests suitable solutions.

The present study considers carrying out an overall analysis of Mediterranean stocks as a priority to investigate the overall spatio-temporal trend of indicator stock status and to discover what is occurring at Mediterranean level. Furthermore, this study also aspires accomplishing stock-by-stock analysis to highlight the stock specificity by trying to analyze biomass, recruitment and exploitation indicators to understand what is happening at stock level.

Complementary to indicator based stock assessments (F, SSB, R), the trend on total landing aggregated at regional and sub-regional level were also explored to point the temporal variability in catches and hence identify the MSY of Mediterranean fisheries. The maximum Sustainable yield is defined as the largest amount of fish that can be taken out of the water, while still leaving enough to ensure sustainability (FAO, 2006-b). Moreover, the analysis was also enhanced by other relevant data on the examined fisheries such as the catch composition, the fishing grounds, the spawning and nursery areas as well as the comparison with similar work performed elsewhere.

2.4.5. Meta- analysis of Mediterranean stock status

a. Current status analysis

With the aim to carry out an overall analysis of Mediterranean current stocks status which based not only on the most reliable data but also that encompass the maximum possible number of Mediterranean stocks, the most recent endorsed stock assessments by both SAC of GFCM and STECF of European commission were consulted and included in the analysis. The assessment results, notably the fishing mortality (F or E) and stock size (TB or SSB) indicators as well as the associated reference points were collected from their official reports available on the STECF website and GFCM SharePoint.

Some rules were followed to select the included stocks. First, a table encompassing the set of the most recent validated assessments by SAC was prepared based on several checks on the SAC published reports and GFCM working group on stock assessments (WGSA) final reports. Indeed, a given assessment is considered still valid if it has been carried out and validated from 2009 onwards, in accordance with included stocks in the first edition of SOMFi (FAO, 2016-a). Thus, all the assessment with a reference year before 2009 are excluded from the analysis of Mediterranean current status. Moreover, a stock was included if at least one reference point is defined or the available data allows in estimate it (F_{MSY} or/ and B_{PA}).

Then, all the STECF published reports available on their website were consulted and the most recent validated assessments were extracted following their reference year of data used. To avoid including one stock twice, the assessment carried out with the most recent data (the assessment reference year) either endorsed by SAC or STECF was selected.

In total 84 stocks are considered in this analysis, 11 from them are small pelagic stocks, mainly sardine and anchovy fisheries, and 73 are demersal stocks of 21 different species. Among the total included stocks, 57 are from SAC endorsed assessments (Tab.3)

About the reference points used to perform this analysis, both regional organization use F_{MSY} or its proxy as a fishing mortality reference point and hence they were available in the published reports cited above. While, as introduced in the previous session (2.2), the established B_{PA} were collected from SAC and STECF reports, the 66th percentiles of biomass estimated from the time series resulted from the assessment was used as B_{PA} proxy for demersal stocks.

To explore the status of the latest validated assessments, both indicator of fishing mortality applied to the stock (F or E) and indicator of stock biomass (TB or SSB) were compared to their associated reference point, mainly F_{MSY} proxies ($F_{0.1}$ or $E_{PATTERSON}$) and the biomass reference point (B_{PA}), respectively. This comparison was facilitated using the ratio of F/F_{UNIQUE} and of B/B_{PA}, which were computed across all stocks (for which a reference point is defined or data allow to estimate it). F_{UNIQUE} refers to either F_{MSY}, $F_{0.1}$ or $E_{PATTERSON}$ depend on which one of them is available. The current estimates of the biomass indicator are used in terms of total biomass or spawning stock biomass depend on which reference point are established and reported to GFCM.

All the 84 stocks are included in the exploitation status analysis thanks to the availability of the fishing mortality reference point (F_{MSY} or its proxy). While, only 57 stocks were retained to perform the biomass status analysis due to the unavailability of biomass reference point. Out of the 57 included stocks in the biomass status analysis, 7 are small pelagic stocks, exclusively sardine and anchovy, and 50 demersal stocks derived from 12 species.

The state of exploitation and the stock size were assessed separately and combined using a *(i)* traffic-light approach and *(ii)* Kobe plot, respectively. These methods are based on the status of the indicator of overexploitation, mainly B/B_{PA} and F/F_{MSY}.

The overall status of Mediterranean stocks was explored at different level by combining the indicators (B/B_{PA}, F/F_{MSY}, the percentage of stocks inside or outside safe limits and percentage of the number of stocks above or below F_{MSY} and B_{PA}) at regional, sub-regional, functional groups, species and stock level.

The arithmetic mean was used to perform the aggregation of exploitation and biomass ratio at the different scales. However, the mean summarizes the set of data into one value assuming that the data is more or less the same, but is not always the case. In this regard, the set of indicators values were graphically depicted through the method of boxplot. The boxplot represents graphically the five number summaries, namely the minimum and the maximum observed vales as well as the first (Q1), the second (median) and the third quartiles (Q3). Moreover, the boxplot summarizes the data in a way that shows how scattered the values are and how much they differ from the mean value.

To measure the set of values spread, some indicators was computed. Among them the range that is equal to the maximum observed value minus the minimum one and the Inter-Quartile Range (IQR). The IQR is the difference between the upper (Q3) and lower (Q1) quartiles, and describes the middle 50% of values when ordered from lowest to highest (Fig.12).

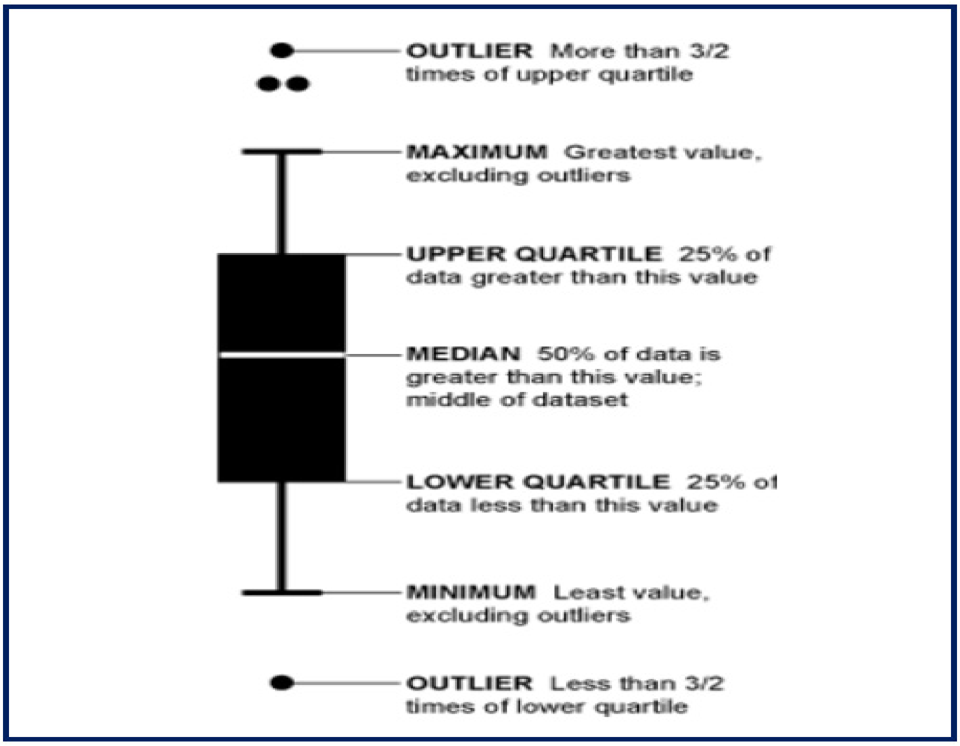


Figure 12: Boxplot explanation

Unidimensional status

The so called "traffic-light approach" refers to the assessment of the estimates exploitation (F/F_{UNIQUE}) and biomass (B/B_{PA}) ratios graphically by dividing the plot on two areas ("Green "are "red') separated by the line $F=F_{UNIQUE}$ (or $B= B_{PA}$ in the cases of biomass), which constitutes the limit between the overexploitation ($F/F_{UNIQUE} >1$ or $B/B_{PA}<1$) and the sustainable exploitation ($F/F_{UNIQUE} <1$ or $B/B_{PA}> 1$) status. This approach served to situate more easily the stock status, stocks in the "'red area" are in undesirable status while, stocks falling within the "green area" are sustainable exploitation (Fig.13).

To point out the most overexploited stock as well as the Mediterranean stocks in the most hardly overexploited, the biomass ratio (B/B_{PA}) and exploitation ratio (F/F_{UNIQUE}) were aggregated by species across all examined stocks, using the arithmetic mean.

Given that the stock status is better described when is expressed in terms of both biomass and exploitation intensity, Kobe plot was used to plot the trend of F/F_{UNIQUE} and B/B_{PA} ratios for all examined stocks.

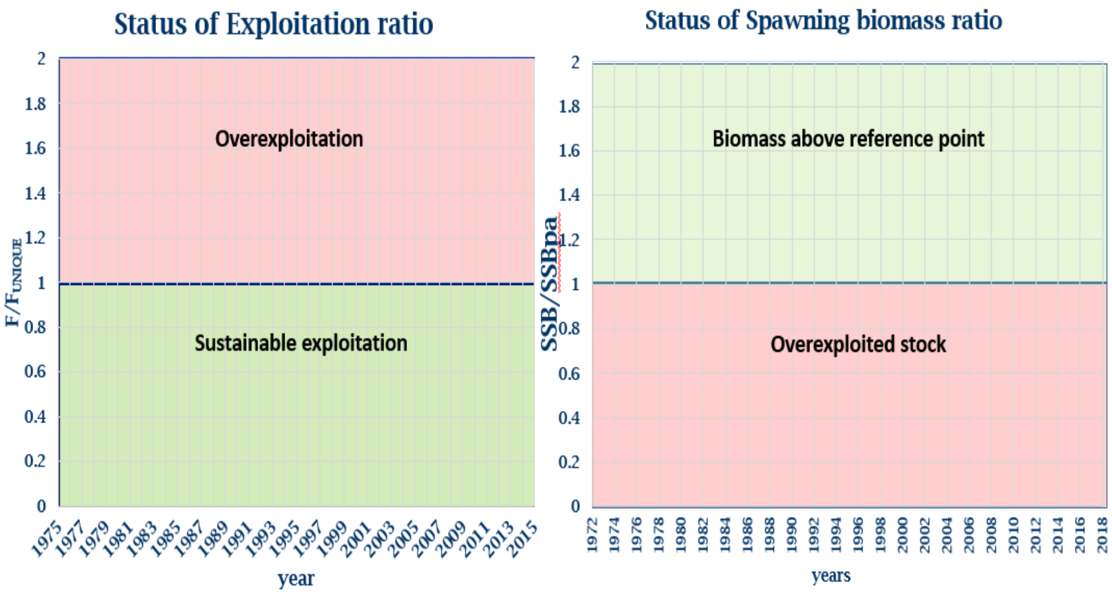


Figure 13: Assessment of exploitation (left panel) and biomass (right panel) ratio applying the traffic-light approach.

Bi-dimensional status

Kobe plot is a simple way to summarize results from stock assessments and to represent the evolution of the stock status in term of both stock size and fishing mortality in relation to the reference point, F/F_{UNIQUE} and B/B_{PA} ratios with values of F/F_{MSY} over 1 indicates that the overfishing is occurring and with values of B/B_{PA} below 1 indicates that the stock is overfished.

This plot is divided in four colorful quadrants each representing a different stock status resulting from the combination between biomass and exploitation ratios state.

Involved from the precautionary principle and in accordance with GFCM framework for providing advice on stock status (document GFCM –SAC16-2014-6-e), the situation when $F/F_{MSY} > 1$ and $B/B_{PA} > 1$ which indicate a status of overfishing was considered in this study as a bad stock status and actions should taking instead an alarming status in the traditional Kobe plot. Hence, the traditional Kobe plot which have four quadrant with "red-yellow-green"colors, was adapted to visualize the precautionary approach with a new fourth color (red-clear) which indicate a worrying status (Fig.14).

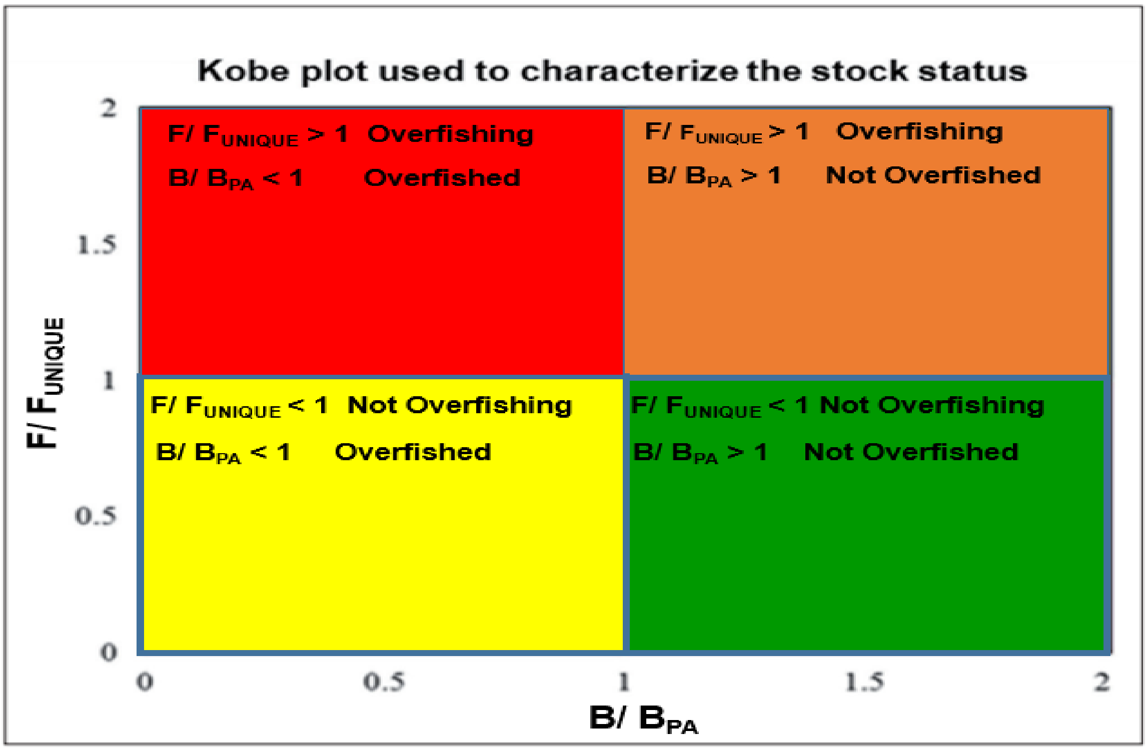


Figure 14: Kobe plot from Arrizabalaga *et al.*, 2007 modified

In this paper, the unidimensional as well as the Bidimensional stock status analysis were provided by species and by sub-area too i.e., Western, Central and Eastern Mediterranean as well as the Adriatic Sea, which helped investigate the current status not only at sub-regional level but also at the stock level.

Table 3:The latest validated stock assessments by SAC (in blue) and by STECF (in yellow) included in the overall analysis of current Mediterranean stock status. In yellow: the STECF validated assessments, in blue; SAC endorsed assessment.

Sub-region	Western Mediterranean											Central Mediterranean								Adriatic Sea		Eastern Mediterranean					
Species / GSA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	19	20	21	17	18	22	23	24	25	26	27
A. foliacea									2015	2014	2014				2010	2010	2014				2014						
A. antennatus	2015				2015	2015			2015																		
B. boops			2009																						2010		
D. labrax							2015																				
E.encrasicolus	2009					2015	2015		2015							2012				2015	2015						
G.melastomus									2010																		
G. seabream							2015																				
L. piscatorius	2015				2015	2015	2015																				
L. budegassa	2013				2013	2013									2010	2010											
M. poutassou						2013			2013																		
M. merluccius	2015		2015		2015	2015	2015		2015	2013	2014	2015	2015	2015	2015	2015	2014			2015	2015						
M.stebbingi																										2015	
M. barbatus	2014		2014	2014	2012	2015	2015		2010	2013	2012		2014	2014	2015	2015	2012			2015	2015				2015		
M.surmuletus	2014				2015				2015						2012	2012									2010	2013	
N. norvegicus					2011	2015			2015						2012	2012				2015	2015						
P. bogaraveo	2011		2011																								
P.erythrinus															2011	2011											
P. longirostris	2015		2011	2011	2012	2014			2015	2015		2015	2015	2015	2015	2015	2015			2015	2015						
S. pilchardus	2015		2015			2015	2015									2014				2015	2015						
S. undosquamis																										2013	
S. solea																				2015							
S. smaris																									2015		
S. mantis									2010											2011	2014						
T. trachurus									2015	2015	2015																

a. Regional temporal trend of stock status

One of the purpose of the present work is to explore the temporal trend, up to 2015 include, of the stock status of Mediterranean stocks at whole. To meet this objective, we proceeded using two different manners. The first approach produced a combined time series of each one of the main indicators of stock status, namely the SSB, R, and F from a numerous time series of individual stocks which allowed analyzing the evolution of the reproductive capacity, the juveniles and the exploitation status of Mediterranean stocks at whole. While, the second approach provided the evolution of the proportion of stocks above, at and below the safe biological limits over times.

The indicators temporal trend

Using the table 5, all the time series of F, SSB and R up to 2015 include of latest validated assessments were collected. Moreover, to be selected, the collected latest stock assessment must produce at least one indicator time series (F, SSB or R). This resulted in getting in total 36 time series of Fishing mortality (F), 34 of Recruitment (R) and 32 of the adult biomass (SSB).

The indicator of biomass (SSB) as well as of the fishing mortality (F) are scaled by dividing each value by its associated reference point (SSB/SSB_{PA} and F/F_{MSY}). Giving that no reference point is defined for the recruitment, the long-term annual mean was used to scale this indicator. Afterwards, the annual mean cross stock over the time series was used to aggregate each indicator which allowed obtain three-time series resulted from a considerable number of individual examined stocks (Tab.4).

Moreover, the exploitation (F/F_{MSY}) and biomass ratios (SSB/SSB_{PA}) aggregated time series were broken down by functional groups, i.e. (i) small pelagic, (ii) demersal bony fish and (iii) crustacean. This allowed exploring the temporal change in each functional group and detect which of the Mediterranean species group status is improving. In addition, the functional groups temporal trend was further broken down by species to explore what is occurring at inside the groups of species

The simple linear regression is used to explore the trend; the R-square as well as the P-value are computed to verify the trend consistency and significantly. Moreover, the percentage of change was also used to explore the degree of change over time. The following formula was used:

Percentage of Change (%) = (Final value –initial value) / initial value *100

Table 4: Method of Aggregation of indicators at regional level.

The assessed criteria	Number of time series included	Standardizing method	The indicator adopted	Aggregation
Reproductive capacity		Reference point (SSB_{PA})		Annual mean across stocks
Recruitment		Dividing by the long term mean	R index (R /mean R)	
Exploitation intensity		Dividing by F_{MSY} proxy	F/ F[illegible]	

Species	Common name	Code	GSA	Sub-region	Endorsed by	Time series		Reference point	
						Start	End	Bpa or *B 66th	F MSY (or its proxy)
A. antennatus	Red shrimp	ARA	1	W	SAC	2002	2015	540*	0.5
		ARA	5	W	SAC	1996	2015	623.2*	0.31
		ARA	9	W	SAC	2005	2015	588.7*	0.32
A. foliacea	Giant red shrimp	ARS	9	W	SAC	2006	2015	163.4*	0.59

Table 5: Stocks included in the temporal trend analysis

E.encrasicolus	Anchovy	ANE	9	W	STECF	2006	2015	not defined	0.4
		ANE	6	W	STECF	2002	2015	45440	0.39
		ANE	17–18	AS	SAC	1975	2015	91872	0.554
M.barbatus	Red mullet	MUT	6	W	SAC	1996	2015	1103*	0.449
		MUT	7	W	SAC	2004	2015	415.38*	0.35
		MUT	15-16	C	SAC	2006	2015	3021.96*	0.45
		MUT	17	AS	SAC	2000	2015	4744.3*	0.45
		MUT	18	AS	SAC	2003	2015	1958*	0.3
		MUT	25	E	SAC	2005	2015	64.6*	0.32
M.merluccius	European hake	HKE	1–3	W	SAC	2007	2015	551*	0.2
		HKE	5	W	SAC	1980	2015	295*	0.17
		HKE	6	W	SAC	2002	2015	2324*	0.2
		HKE	7	W	SAC	1998	2015	1638.58*	0.15
		HKE	9	W	SAC	1985	2015	21597.8*	0.24
		HKE	12–16	C	SAC	2007	2015	7400.24*	0.15
		HKE	17–18	AS	SAC	1998	2015	101766*	0.21
M. surmuletus	Striped red mullet	MUR	5	W	SAC	2000	2015	182*	0.13
		MUR	9	W	STECF	2006	2015	579.6302*	0.52
N.norvegicus	Norway lobster	NEP	9	W	STECF	2005	2015	282.932*	0.194
		NEP	11	W	STECF	2005	2015	61.26*	0.19
		NEP	17–18	AS	STECF	1975	2015	6355	0.388
P. longirostris	Deep water rose shrimp	DPS	1	W	STECF	2003	2015	173.2652*	0.87
		DPS	9	W	SAC	2006	2015	1013.1*	0.71
		DPS	9–11	W	STECF	2006	2015	1742.06*	0.91
		DPS	12–16	C	SAC	2007	2015	14618.2*	0.84-0.93
		DPS	17–18	AS	SAC	1998	2015	641*	0.9
		DPS	19	C	SAC	2007	2015	313*	0.89
S. solea	Common sole	SOL	17	AS	SAC	1980	2015	9940.469*	0.26
S.pilchardus	Sardine	PIL	01–3	W	SAC	2010	2015	not defined	0.79
		PIL	6	W	SAC	2004	2015	not defined	0.32
		PIL	17–18	AS	SAC	1975	2015	250636	0.715
T. trachurus	Horse mackerel	HOM	9–11	W	STECF	1975	2015	not defined	0.4

Trend on proportion of stock status

This approach is based on the transformation of the stock status across years and GSAs to a time series of annual stock status proportions. To get this, the published reports of SAC of GFCM and the STECF of EC were consulted which served to get the stock status definition of the whole annual endorsed assessments performed over the period 2006-2015 (reference years of performed assessment). Then, the great number of stock status possibilities was reduced through establishing three main stock status categories, namely (i) stocks below, (ii) at and (iii) above safe biological limits. Stocks below safe biological limits encompass the stocks underexploited (U), moderately (M) and sustainably exploited (S). While, the second category involves stocks for which no farther room is expected, especially the cases of stocks Fully exploited (F) and stocks In Risk of Overexploitation (in risk of O). The third category group all deteriorated stocks either defined as Overexploited (O), Depleted (D), Ecologically unbalanced (E), and stocks in Low biomass level (L).

In other words, for a given reference year, following its stock status (sustainably exploited, fully exploited, overexploited, depleted, etc.) as it was defined by SAC or STECF, each stock is attributed to one category. Then, the total number of stocks belonging within each category was transformed to a percentage from the total endorsed assessments for this year. In the same way, the proportion of stock status over years were counted and, hence, three time series that corresponding each one to a stock status category was obtained. Eventually, the times series were plotted to analyses the evolution of Mediterranean stock status across years.

2.4.6. Stock-by-stock analysis

The stock by stock analysis was applied to some selected stocks, mainly two out four Mediterranean fisheries under GFCM multi-annual management plan, namely the stocks of Deep-water rose shrimp and European hake in the strait of Sicily and the fishery of small pelagic in the Adriatic Sea (sardine and anchovy). In fact, the fisheries of small pelagic in the Adriatic Sea was selected given that is the first stock that benefited from the implementation of a multi annual management plan in 2012, so we expect detect if an improvement in the stock status occur. While, the second fishery was chosen due to its high importance, in terms of value and production, in the studied area in addition to the advantage of data availability compared with the other stocks.

Comparative analysis

One of the main goals of the present study is testing the robustness and consistency in predicting the time series of state and pressure indicators in successive years. For this reason, we confront the time series from one run (the last validated assessment) and from annual validated assessments, which is generated by the collect of the current value of indicator of stock status (F, SSB, TB and R) reported each year.

Furthermore, in this study, the historical retrospective analysis is conducted by examining the results of each final assessment conducted during the four last years (2012- 2015) applying the same model to assess the considered stock. This comparison is important to check the consistency of the model to generate a time series of biomass and fishing mortality indicators year after year through the studied period and determining whether there was a consistent pattern of overestimating or underestimating assessment results in the successive years.

A retrospective pattern is defined as a systematic inconsistency among a series of estimates of population size, or related assessment variables, based on increasing periods of data (Mohn, 1999). In fact, there are two types of retrospective patterns, (i) historical and (ii) within-model. The within model retrospective analysis is routinely used by the national GFCM members experts to determine the internal inconsistency in the data.

Given the inconsistency between the successive assessments and between time series from last assessment and that resulted from the collect of annul estimates of current values, in this study, the analysis of stock size and fishing mortality status will be based on the time series from last validated assessment (one run). The indicator time series from one run use allows in reducing the variability linked to the stock assessment model and the reference points change from one assessment to another.

Stock status

The assessment of stock status was carried out applying both the unidimensional and bi-dimensional stock status using the traffic-light approach and Kobe plot.

Exploitation intensity of each stock are expressed as the fishing mortality (F), exploitation ratio (E) and as exploitation ratio (F/ F_{UNIQUE}) with F_{UNIQUE} refers to F_{MSY} or its proxy $F_{0.1}$.

Moreover, the ratio of the exploitation (F/F_{UNIQUE}) was calculated over years and compared with 1.66 and 1.33 to highlight on the overexploitation levels; the values of F/F_{UNIQUE} below 1.33 indicate a state of low overfishing, values of F/F_{UNIQUE} ranged between 1.33 and 1.66 corresponding to an intermediate overfishing, while a value of exploitation ratio above 1.66 confirm that the high overfishing status is occurring.

The examination of stock size status is based on a simultaneous analysis of both trend of Spawning Stock Biomass indicator which illustrate perfectly the stock reproduction capacity and the Recruitment Index (R) indicator that indicate the future generation quantity. This analysis helped to identify the recruitment overfishing through the time series and used to understand the stock response with regard to the exploitation intensity. The biomass ratio (B/B_{PA}) which is expressed in terms of total biomass or spawning stock biomass, depending on which reference point are available in the SAFs, was also used to assess the stock size status over the examined period.

All the reference point and indicator used to assess the status of examined stocks are extracted from their assessment reports (SAFs)

Given that the stock status is better described when is expressed in terms of both biomass and exploitation intensity, Kobe plot was used to plot the trend of F/F_{UNIQUE} and B/B_{PA} ratios for all examined stocks which served to perform the Bi-dimensional Stock Status (BSS)

2.4.7. Assessed stocks contribution to Mediterranean production

To examine the capacity of the assessed stocks to reflect on the state of Mediterranean stocks, the aggregated landing by sub-region as well as the landing of each assessed species by sub-region were studied. The current commercial catch (2014 is the most recent year available in the database) was uploaded from GFCM capture production database available on the site web: http://www.fao.org/fishery/statistics/GFCM-capture-production/query/fr.

Total landing in the Mediterranean sub-regions was provided in terms of both tons and percentage of each region from the total Mediterranean landing. Further, the percentage of the reported landing of species included in the analysis was provided by sub-region which allowed highlight on the ability of examined stocks to report on the sub-regional overall status.

The number of assessed stocks by sub-region as well as their contribution to the sub-region landing were explored, included also those stocks for which never have been produced a validated assessment. This kind of analysis is important to examine the assessed species proportion from the total and verify their ability to represent stock status at sub-region level.

3. Results

3.1. Mediterranean production

3.1.1. Evolution of the regional and sub-regional marine production

The Mediterranean marine capture production followed a significant (R squared equal to 0.93) upward trend over the period 1970-1994 reaching a peak of about 1 087 448 tons in the end of this period, except in 1990 when an apparent drop was recorded. This drop is especially evident in the Western Mediterranean production. Further, the Adriatic Sea landing showed a significant decrease during the period 1984-1990 that occurred after reaching its peak in 1984. This decrease is stabilized from 1990 onwards. However, no evident decrease was shown in the other Mediterranean sub-regions landings. The Mediterranean total production seems to be recovered during the period 1991-1994 when the production was increased at a rate of about 10%. In effect, the Western, the Central and the Eastern Mediterranean production were shown an apparent increase in this period. Since that, a continuous declining trend is observed in the regional total landing except in 2006 when a second peak of about 1 034 476 tons, less important than the former one, was recorded (Fig.15).

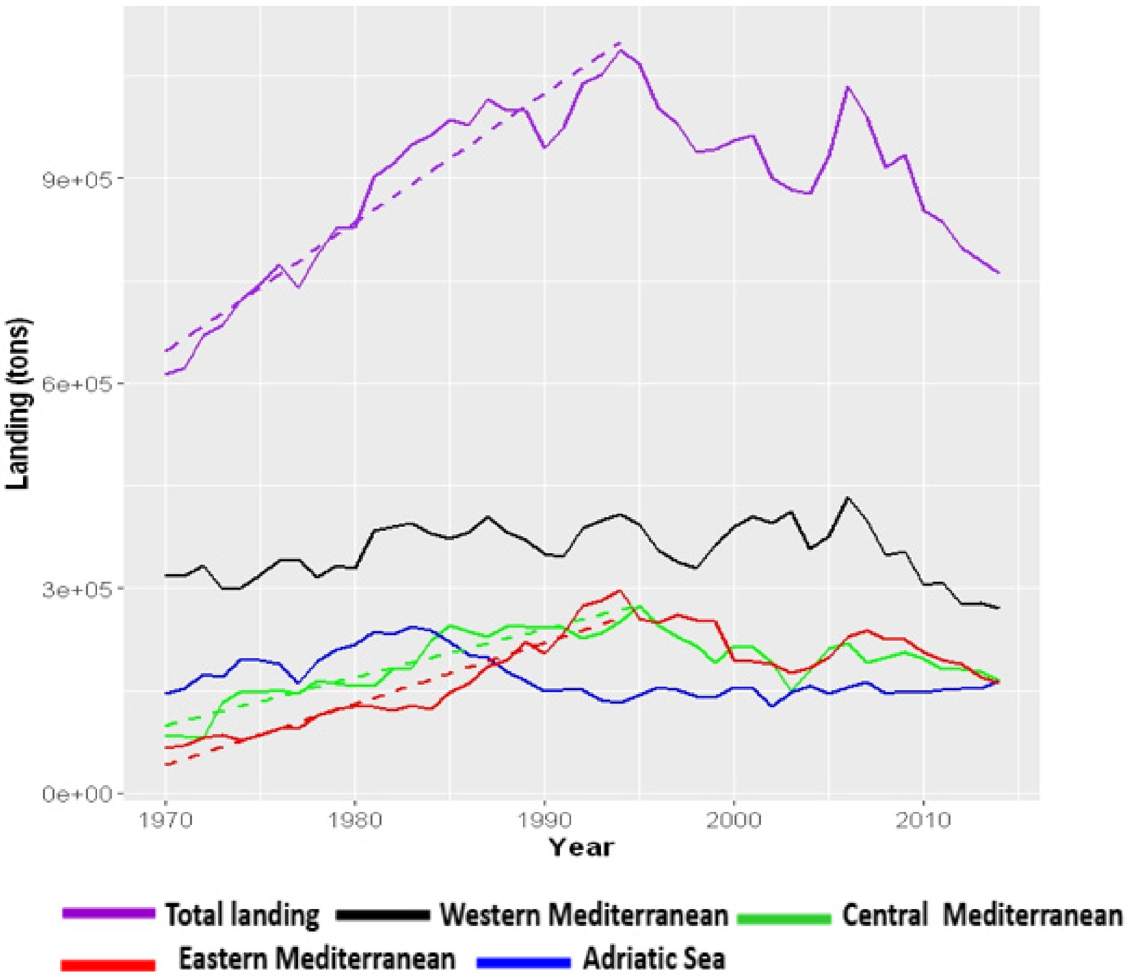


Figure 15: Trend in regional and sub-regional Mediterranean Total Landings (TL) indicator between 1970 and 2014. the dotted lines refer to the linear regression line.

The trend of the sub-regional Mediterranean marine production

The Western Mediterranean marine landings were about 320 000 tons in the beginning of 70s, then it raised steady reaching a value of about 381 624 tons in 1987. Afterwards, apparent fluctuations were observed that continued until 2004. Then, a peak of about 432 493 tons was reached in 2006 followed by a significant downward trend (R squared equal to 0.90 and P-value equal to 7.341e-05 for the period 2006-2014) (Fig.15). This peak is observed notably in the small pelagic landings, including the species groups of herrings, sardines and anchovies. These species group contributes with about 60% to total Western Mediterranean landings and follows exactly the same overall trend as this sub-region total landing (Fig.16-a).

From the start of the examined period until the 80s, the total Adriatic Sea marine production showed an upward trend (R2: 0.589, p-value: 0.001353), except in 1987 when a drop is observed that was especially shown in the species groups of herrings, sardines and anchovies. The Adriatic production is stabilized in an average value of about 359 037.28 tons from 90s onwards. In fact, in that period, the production of the species groups of herrings, sardines and anchovies was raised apparently. However, the production of molluscs group was declined (Fig.15; Fig.16-b).

The Central Mediterranean landing increased steadily from its minimum reported production of about 83 884 tons in 1970 to its historical level of about 273 872 tons recorded in 1995. Afterwards, the marine reported landing was decreased progressively until reaching a minimum value of about 149 652 tones. This drop is mainly shown in the small pelagic landings. An improvement was detected in the following years especially in 2006; this improvement is recorded mainly by the species groups of herrings, sardines and anchovies. Recently (from 2009), the central Mediterranean production returned to decrease (Fig.15; Fig.16-c).

Likewise, the Eastern Mediterranean marine production follows a significant (R squared equal to 0.90) upward trend from the beginning of the time series to 1994. Since that, a relevant decrease is shown. This increase is specially observed in the groups of (i) herrings, sardines, and anchovies and in (ii) the miscellaneous coastal fish (Fig.15; Fig.16-d).

Sub-regional landing composition

In general, the Mediterranean catches are very diverse; however, they are by far dominated by small pelagic group, especially the species groups of herrings, sardines and anchovies.

The Western Mediterranean recorded landings were on average about 274 923 tons for the period 2012-2014. This production is dominated by the small pelagic group (all species included) accounting for about 60% to this sub-region total landing. Followed by the molluscs and the crustacean that contributed with about 7% and 4% to the average of the last three years Western Mediterranean production, respectively.

In the Adriatic Sea, the species group of herrings, sardines and anchovies makes a considerable contribution up to 60% from the three last years average reported Adriatic marine production (156 934 tons), followed by the molluscs with a contribution up to 20% and the Miscellaneous coastal fish that accounted for about 6%. Together those three groups represent almost 90% of the Adriatic Sea marine production (average 2012-2014) (Fig.17).

In effect, the groups of (i) small pelagic (all species included), (ii) miscellaneous coastal fishes, (iii) molluscs and (iv) crustaceans together accounting for about 80 percent of the Central (174 762.6 tons) as well as the Eastern Mediterranean (173 349.6 tons) catches, which are reported in the last three years (2012-2014 arithmetic mean) (Fig.17).

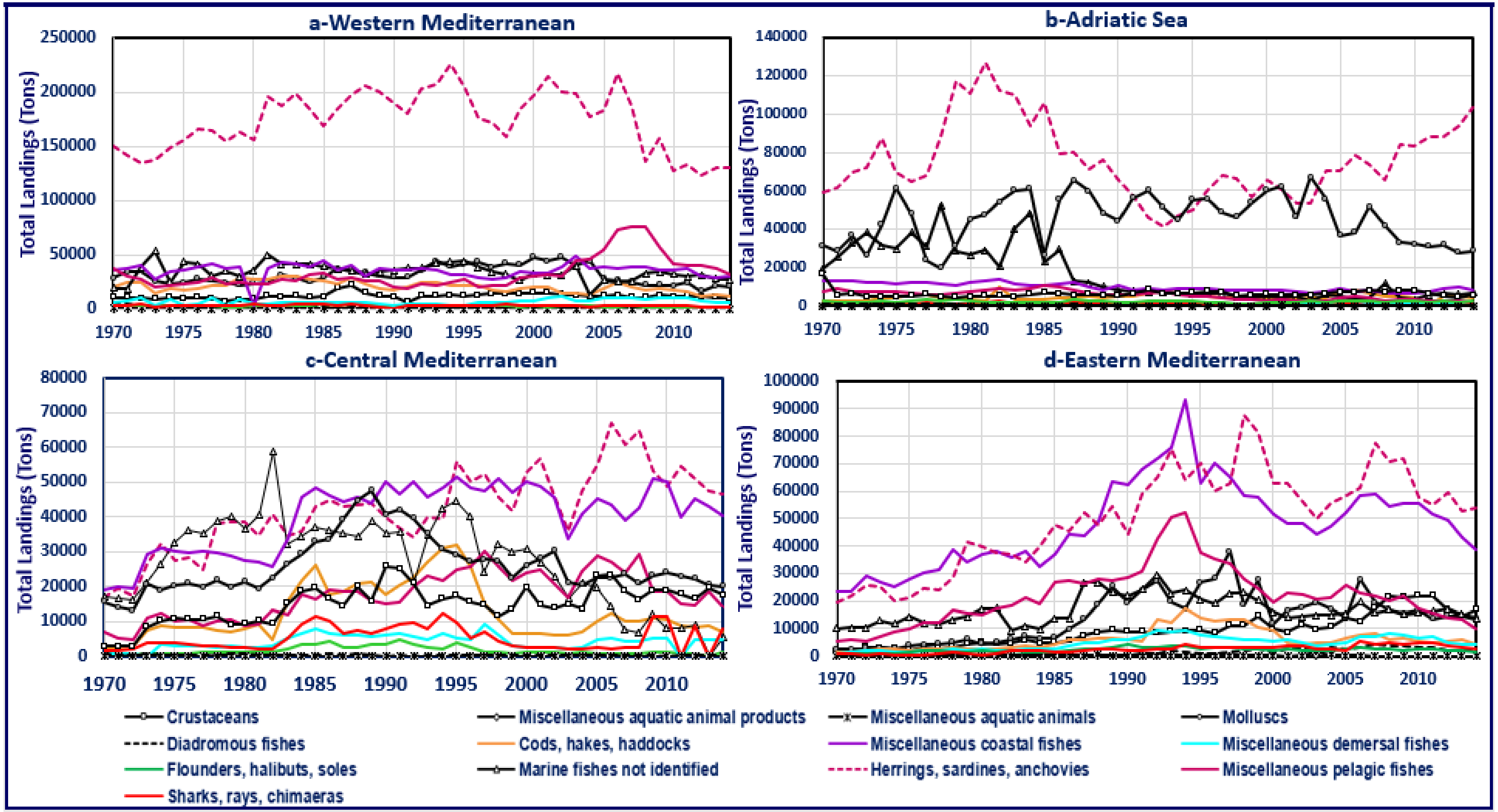


Figure 16: Trend in the Mediterranean sub-regions landings by group of species for the period 1970-2014.

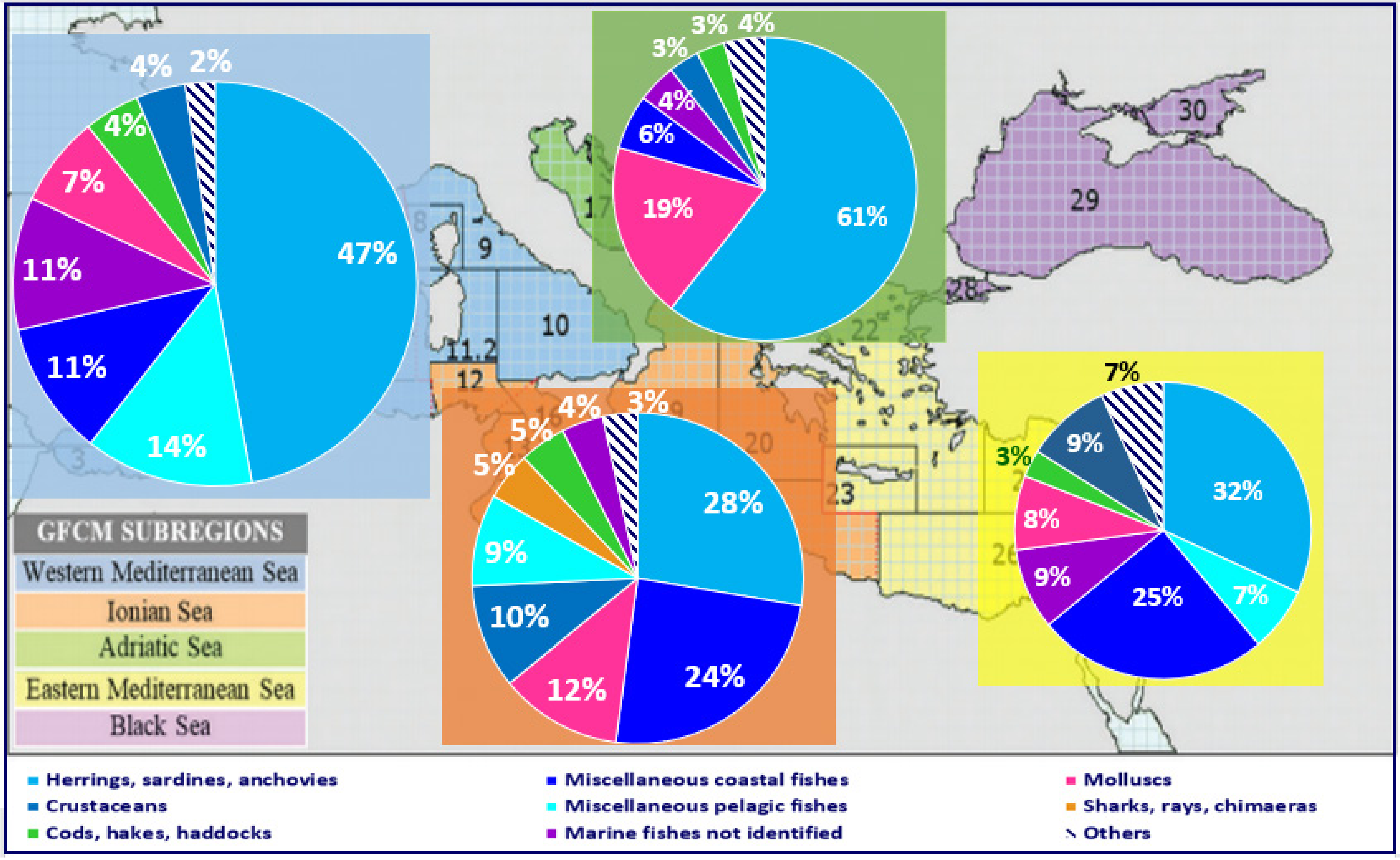


Figure 17: Composition of the Mediterranean sub-regional marine production, based on the average last three years (2012-2014) reported marine landings. Pie charts represented on the GFCM sub-regions map (FAO, 2016-a).

3.1.2. Sub-regional coverage

Evolution of the number of validated assessments

The total number of validated assessments by both SAC of GFCM and STECF of Commission European per year (reference year of performed assessment) shows a considerable increase from the beginning of the time series up to 2009, it passed from 22 to 60. Then it was decreased in 2010 and in 2012 when it reached its minimum value of about 39 validated assessments. Since that time, the number was followed a gradual upward trend. In fact, the number of approved evaluations (with data up to 2015) was at about 51 assessments, include the small pelagic and demersal stocks (Fig.18).

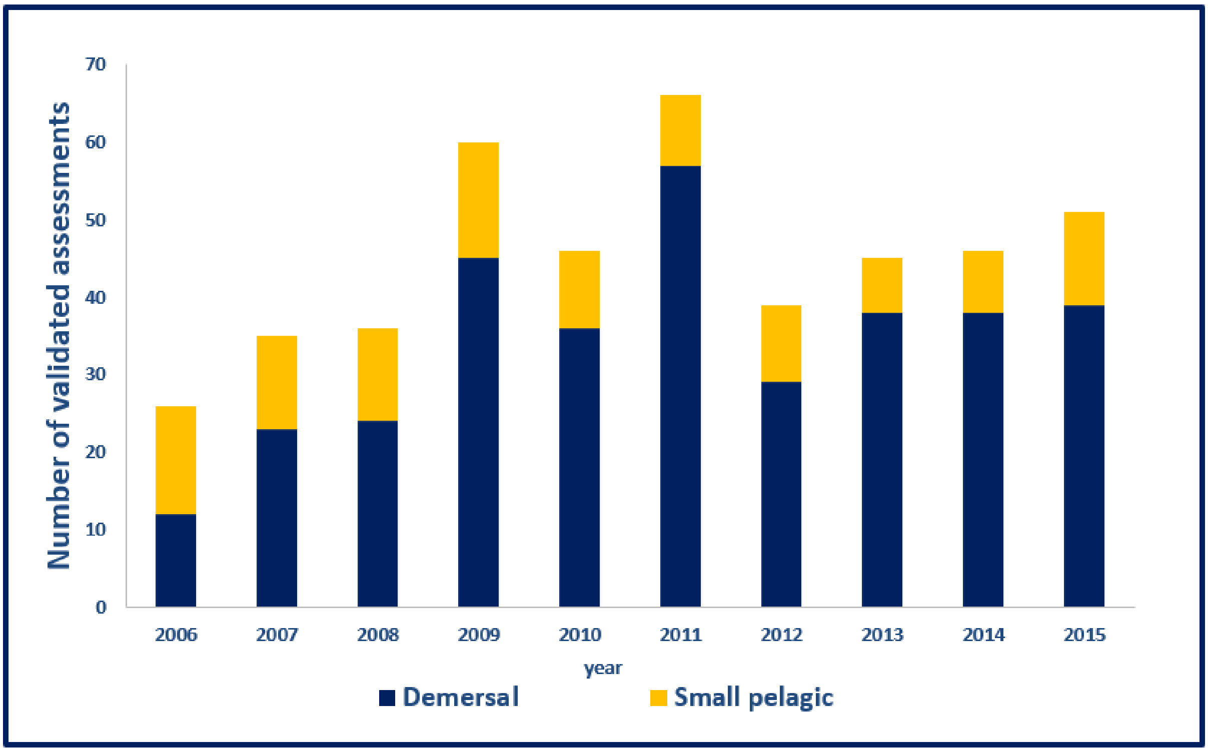


Figure 18: Evolution temporal of the number of validated assessments of Mediterranean stocks either by SAC or by STECF.

The sub-regional coverage of assessed stocks

In 2014, around 28 % out of the recorded total Mediterranean landing come from the Black Sea region, followed by the Western Mediterranean that contributed with a 25.6 % and by the Central Mediterranean and the Adriatic Sea were contributed by a quite similar part to the total catch, which were about 15.59% and 15.57%, respectively (Tab.6).

The assessed small pelagic of the Adriatic Sea contributed with a significant percentage up to 63% to the total landing of this region. While, this species group contributed by no more than 39% and 16% to the total landing reported in the Western and Central Mediterranean, respectively (Fig.19).

The demersal assessed species of each sub-region form a minor part to the total landing of the associated sub-region, they constitute around a 14%, 17%, 8% and 7% to the total landing of Western-MED, Central-MED, Adriatic Sea and Eastern-MED, respectively (Fig.19).

Table 6: Contribution of each sub-region reported landing to Mediterranean total production (source: the GFCM Capture Production database).

Sub-region	Total Landing (2014)	
	Tons	%
Western-MED	270 526	25.60
Central-MED	164 697	15.59
Adriatic Sea	164 474	15.57
Eastern -Med	161 202	15.26
Total Mediterranean production	**1 056 422**	**100%**

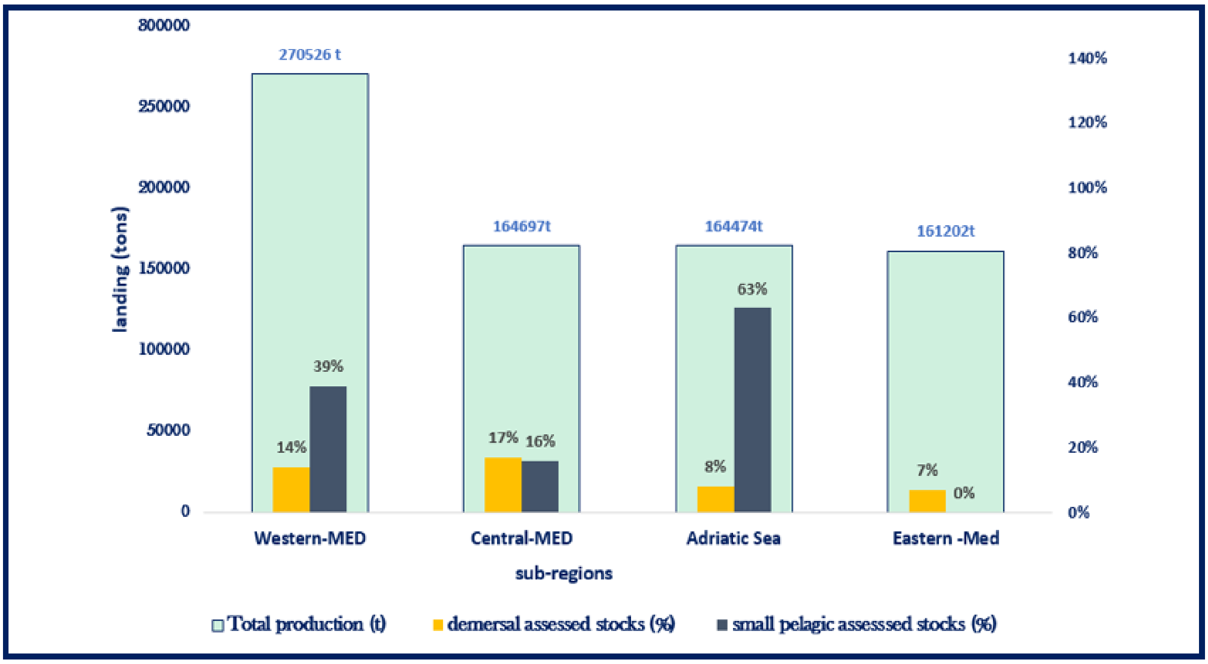


Figure 19: Contribution (%) of the included species in the analysis to the corresponding sub-region reported landings (in 2014).

3.2. Overall status

3.2.1. Status of Mediterranean stocks at regional level

Tacking separately, the percentage of stock harvested unsustainably (87%) is greater than the percentage of stocks (68%) with poor stock size (biomass below the reference level) (Fig. 22).

Based on indicator of stock status (B/B_{PA}), out of the 57 stocks from the entire Mediterranean Sea that were analyzed, two stocks (3.5%) are assessed as fully exploited, 16 (28%) as sustainably exploited, while 39 (69%) stocks are classified as overexploited. In effect, from the stocks having a biomass below the associated threshold reference point (B_{PA} or its proxy), 28% are two times below the B_{PA}, however, 12% are so close to reach the desirable situation (B/B_{PA} >1) given that their biomass ratios are ranged between 0.99 and 0.90. On the other hand, 9% out of the stocks having a biomass above the reference point are so near to fall in the red area ($B/B_{PA}<1$) given that their relative biomass is ranged between 1 and 1.10 (Fig. 20).

According to the indicator of exploitation status (F/F_{MSY}), the vast majority of examined (86%) stocks are harvested above the level that can ensure the stock sustainably, while only a minority (13%) of stocks are exploited rationally. In effect, the overfishing intensity varies from very low ($1.01 \leq F/F_{MSY} \leq 1.10$) to very high ($F/F_{MSY} > 3$). Moreover, out of the 73 overexploited stocks, 15 (21%) are in low overfishing among them 5 (33%) being in a very low overfishing intensity with an exploitation ratio ranged between 1.01 and 1.10, eight (11%) stocks are subjected to an intermediate overfishing ($1.33 \leq F/F_{MSY} \leq 1.66$). While, the majority (68% from the 73 stocks) of Mediterranean assessed stocks are in a high overfishing status among them 24 (48%) stocks are harvested more than 3 times the level that can ensure the stock sustainability (Fig.21).

Furthermore, when both indicators are simultaneously considered, the percentage of stocks within safe biological limits become negligible (9%) compared to the percentage of stocks outside safe biological limits, which was estimated at about 90% (Fig.22).

The aggregated fishing mortality in relation to the target level (F_{MSY} or its proxy) and the relative biomass using the arithmetic mean report that, on average, the Mediterranean assessed stocks are harvested three times greater than the target level and the biomass is lower than the reference point, which indicates a status of overexploitation (Fig. 23). On the other hand, the indicators of dispersion show a high spread of exploitation intensity ratios across the Mediterranean stocks, with ratios range from about 0.010 to 12.80 and a variance up to 6.53. In contrast, the Mediterranean relative biomass is more concentrated around the mean, showing a low variance of about 0.23 and a range of about 2.53 (Tab.7).

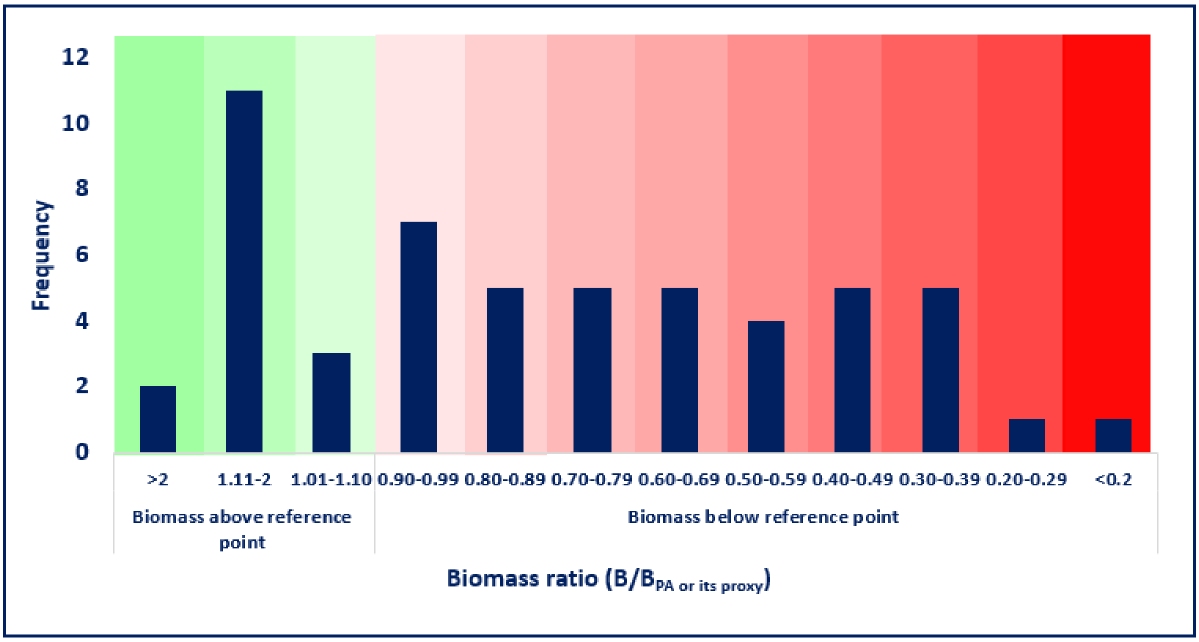


Figure 20: Range of the biomass relative to the threshold reference point (B_{PA} or its proxy). The colored area indicates the exploitation status. Gradual green area: from smaller (clear green) to larger (dark green) B/B_{PA}, gradual red area: from very low (clear red) to hard (dark red) overfished stocks ($B/B_{PA}<1$).

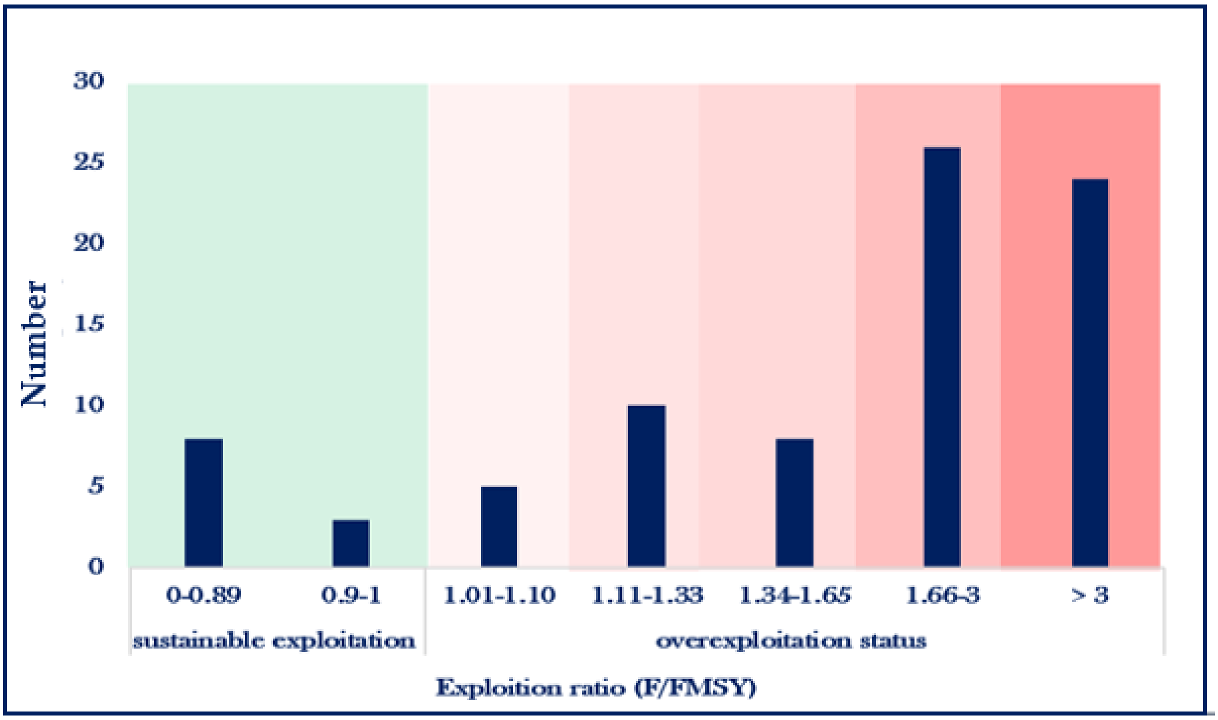


Figure 21: Exploitation ratios range. The colored area indicates the exploitation status. Green area: sustainable exploitation, gradual red color area: from very low (clear red) to hard (dark red) overexploitation status.

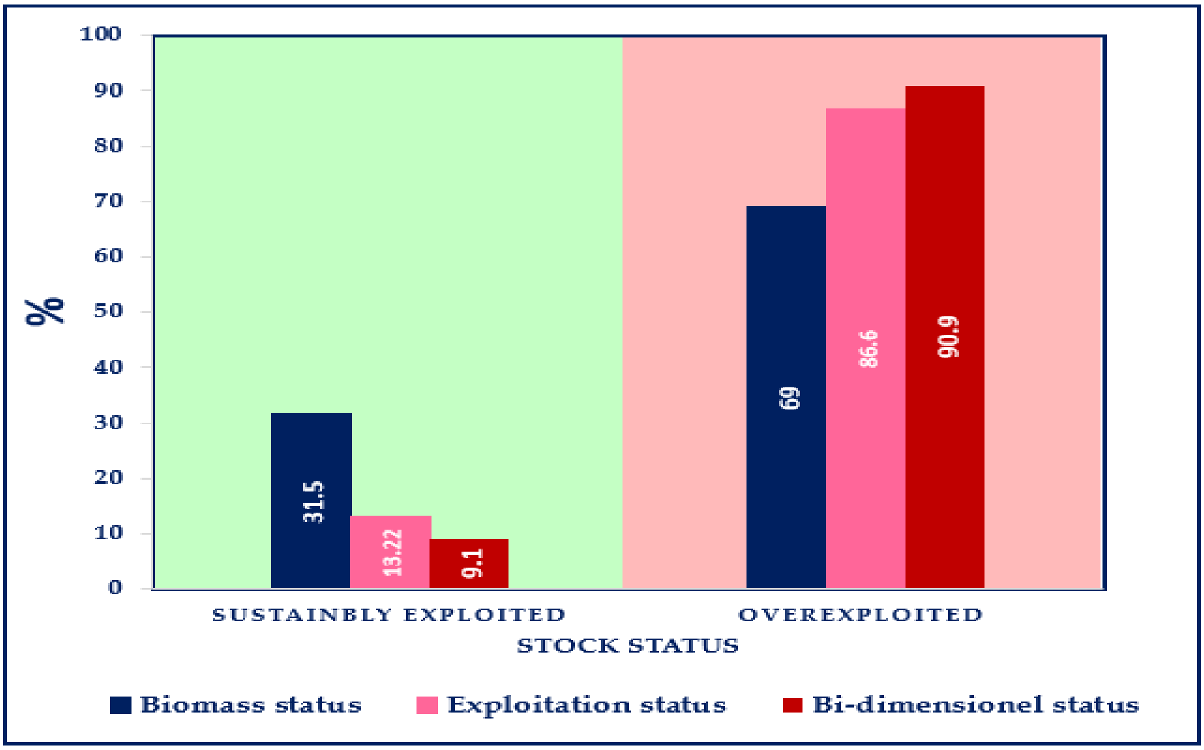


Figure 22: Regional stock status in terms of stock size and exploitation status taking separately and combined. The green area groups the proportion of stocks inside safe biological limits, while the red area encompasses percentages of stocks outside safe biological limits either in terms of fishing mortality, biomass or both criteria.

Table 7:Indicators of dispersion measures computed for the exploitation and biomass indicators

Indicator	F/F_{MSY}	B/B_{PA}
Range	**12.79**	**2.53**
IQR	**1.25**	**0.5225**
Min	**0.010**	**0.1700**
Max	**12.80**	**2.7000**
Variance	**6.53**	**0.23**
SD	**2.56**	**0.48**

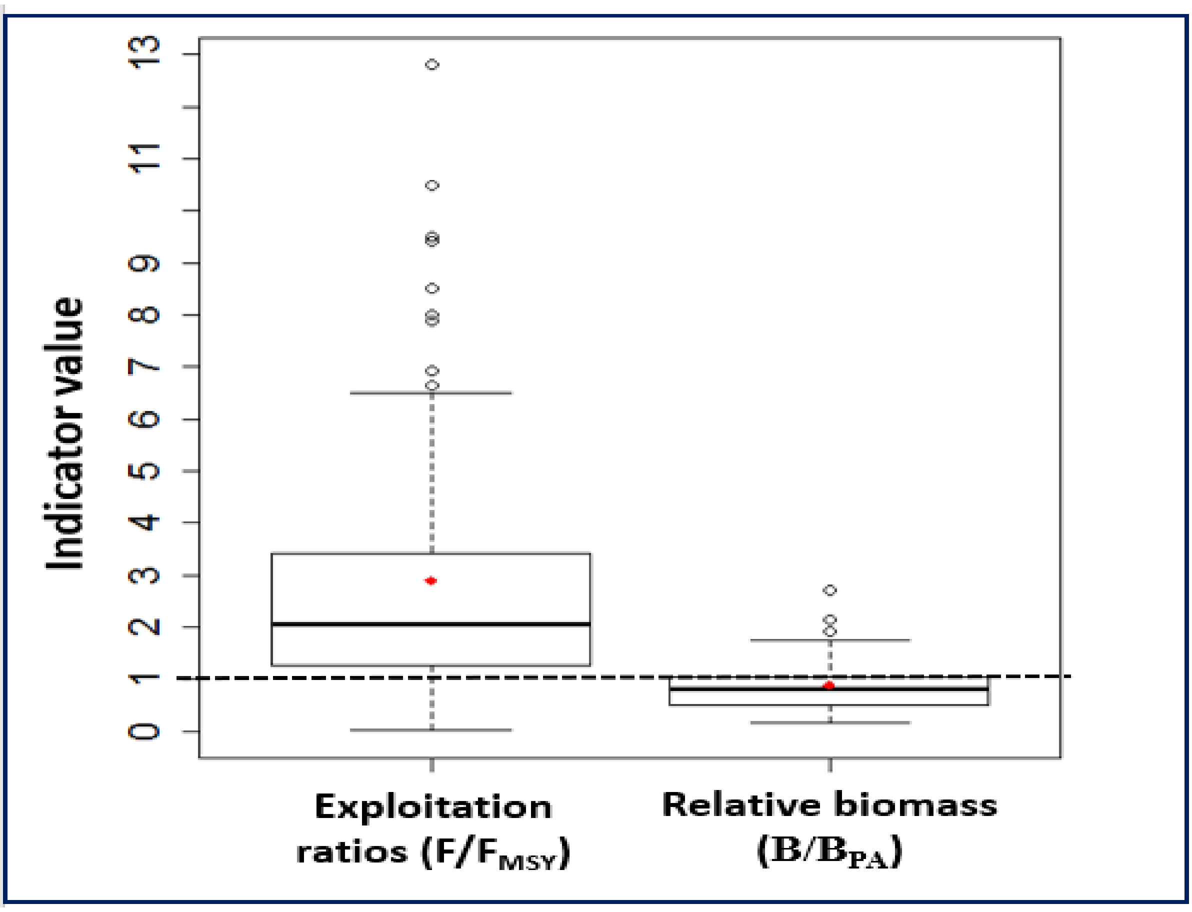


Figure 23: Regional indicators of fishing mortality and stock size. The red points indicate the arithmetic mean.

3.2.2. Status of fish stocks in the northern and the southern shores of the Mediterranean

Out of the 84 assessed stocks in the whole study area, in total 79 endorsed assessments are from the northern Mediterranean shore among them 7 stocks were assessed jointly with southern Mediterranean countries (Alboran Sea and Strait of Sicily) in the frame of FAO regional projects, mainly the FAO CopMed and MedSudMed projects. On the contrary, a few number of stock assessments are carried out from 2009 onwards in the southern Mediterranean shore. In effect, during this period in total only 12 assessments were performed, including the joint assessments with Northern Mediterranean countries (table 3 and table 9).

In terms stock size, on average, the Southern Mediterranean stock biomass is around two times below the threshold biomass reference points. However, the Northern Mediterranean assessed stocks were averaged a relative biomass (B/B_{PA}) around 0,9 indicating that are relatively in a better state of biomass compared with the former group (Southern assessed stocks) although the set of data have a large dispersion (Fig.24-top right).

On the other hand, on average the state of exploitation intensity is slightly similar in the both Mediterranean shores given that both groups of stocks were shown a quite similar F/F_{MSY} aggregated ratio, 2.9 and 3.1 in the Northern and the Southern shore, respectively. Although the set of indicators of Northern Mediterranean stocks have a high difference across GSAs (Fig.24-top left).

Taking those indicators simultaneously, it was revealed that the aggregated assessed stocks belonging to the Northern as well as those of the Southern Mediterranean shore are overfished and they are in the overfishing status. While the Northern stocks are closer to the orange quadrant of Kobe plot indicating that are in a better state of biomass compared with the southern Mediterranean stocks (Fig.24-bottom left).

The indicator of the proportion of stocks assessed as inside safe biological limits (neither overfished nor the overfishing is occurring) illustrates that the Northern Mediterranean shore encompasses the greater number of stocks in a safe state (Fig.24-right).

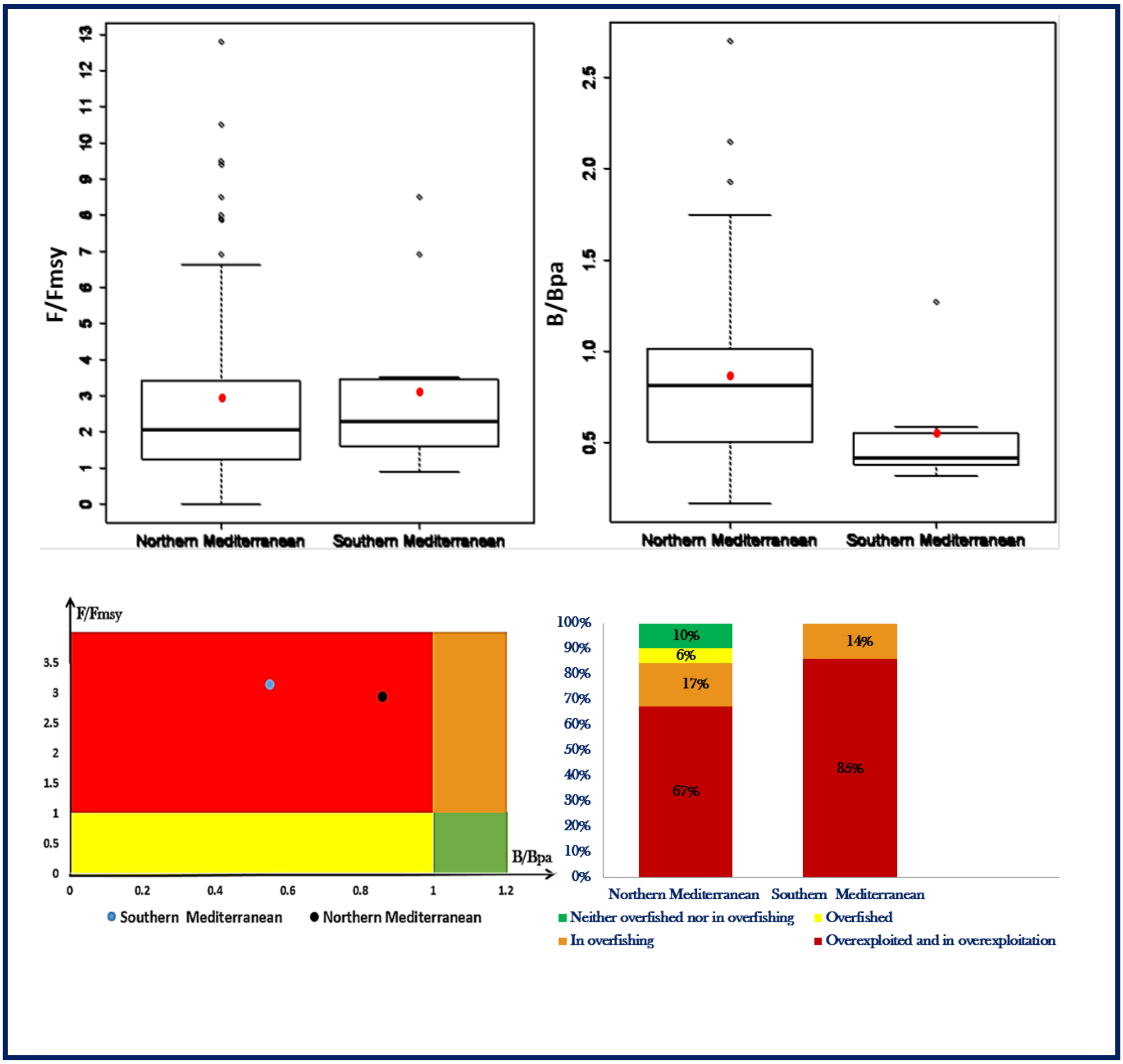


Figure 24: Indicators of stock status aggregated by Mediterranean northern and southern shores. Top panels: boxplots represent the state of biomass and exploitation indicators taken separately with the red dots indicate the mean. Bottom panels: bi-dimensional status of stock size and exploitation indicators taking simultaneously on Kobe plot (bottom left) and the percentage of stocks inside and outside safe biological limits (bottom right).

3.2.3. Status of stocks at sub-regional level

The status of exploitation

Without any exception, all Mediterranean sub-areas are subjected to high overfishing status given that the majority of their assessed stocks are not in accordance with the safe biological limits in terms of either stock size or fishing mortality. In effect, according to the percentage of stocks exploited above the level that can produce the MSY, the Adriatic Sea stocks are in the worst state given that 91% are assessed as unsustainably exploited, followed by the Western and the Central Mediterranean with a percentage estimated at about 88% and 86%, respectively. While, the Eastern Mediterranean remains the less overexploited sub-region that showed the lowest percentage (66%) of deteriorated stocks.

However, the aggregated exploitation ratios (mean F/F_{MSY}) by sub-region indicate that the Western Mediterranean stocks are the most heavily overexploited, with an average fishing mortality around three times higher than the target level, followed by the Central Mediterranean stocks that averaged an exploitation ratio of about 2.9. Then, appear the Adriatic Sea and the Eastern Mediterranean stocks with an average exploitation ratio at about 1.75 and 1.77, respectively (Fig.25-right panel).

In terms of individual stocks, the three most overexploited Western Mediterranean stocks are the European hake, the black-bellied angler and the blue whiting, successively. While, the sardine in GSA 7 and in GSA 1-3, the blue and red shrimp in GSA 9, the stripped red mullet in GSA9 and deep-water rose shrimp in GSAs 9-11 are exploited rationally (table 9).

The *P. longirostris, S. mantis* and *M. merluccius* are successively the severely overexploited stock in the Adriatic Sea, whereas, the European hake, the stripped red mullet and red mullet are the most three overfished stocks in the Central sub-region. The results shown that the red mullet is exploited rationally in the Adriatic Sea as well as the stocks of sardine and the Norway lobster in the Central Mediterranean, notably in GSA 16 and in GSA15-16, respectively (table 9).

Concerning the Eastern Mediterranean stock status, the stocks of *S. smaris* and *M. barbatus* are exploited below the F_{MSY} while, the stocks of *S. undosquamis, B. boops, M. stebbingi* and *M. surmuletus* are harvested unsustainably (table 9).

Status of adult biomass

Out of the nine Adriatic Sea assessed stocks, seven are assessed as overexploited and only two have a biomass above the reference point, especially the case of *M. barbatus* and *A. foliacea*. The spawning biomass of European hake stocks is in an alarming state with a biomass ratio estimated at about 0.29, meaning that the current adult biomass is approximately 3 times lower than the biomass level that can keep the stock reproductive capacity (table 10).

Concerning the Eastern Mediterranean, three stocks (*S.undosquamis, M. stebbingi* and *M.surmuletus*) have an adult biomass below the reference point and two stocks (*M. barbatus* and *S. smaris*) show a SSB above the associated threshold reference point. The lowest adult biomass is observed in the stock of *M. stebbingi* with a relative biomass estimated at about 0.32 (table 10).

About the Central Mediterranean assessed stocks, it was revealed that the small pelagic stocks (sardine and anchovy) have a biomass level above the associated reference point which indicate that are sustainably exploited. In contrast, the majority (60%) of demersal assessed stocks have a current biomass below B_{PA}, meaning that the current biomass level cannot ensure the stock self-renewable capacity. The adult biomass of the red mullet is extremely low (B/B_{PA} =0.17), which suggest a future stock collapse if no action is made. The stocks of European hake in strait of Sicily and giant red shrimp and hake in the Western Ionian Sea are in a good stock size status with an estimated relative spawning biomass of about 1.27, 1.43 and 1.29, respectively. The stock of red mullet in GSA 19 is so close to get the B_{PA} which is an encouragement point to attempt reverse its status by taking some suitable actions.

A great number (75%) of Western Mediterranean assessed stocks have a biomass below the threshold reference point (B_{PA}) indicating that are overexploited. The stocks showing the lowest biomass level are the European hake in GSA07 and in GSA09 followed by the European anchovy in Gulf of Lions and the red mullet in the Ligurian and North Tyrrhenian Sea area (GSA09) (table 10).

Although their biomass is currently above the associated reference point, however, the stocks of red mullet in Balearic Island, sardine in northern Spain and deep-water rose shrimp in northern Alboran sea are currently so close the get the threshold reference point (B_{PA}), which ring alarm bells and put into question the future sustainability of this stock.

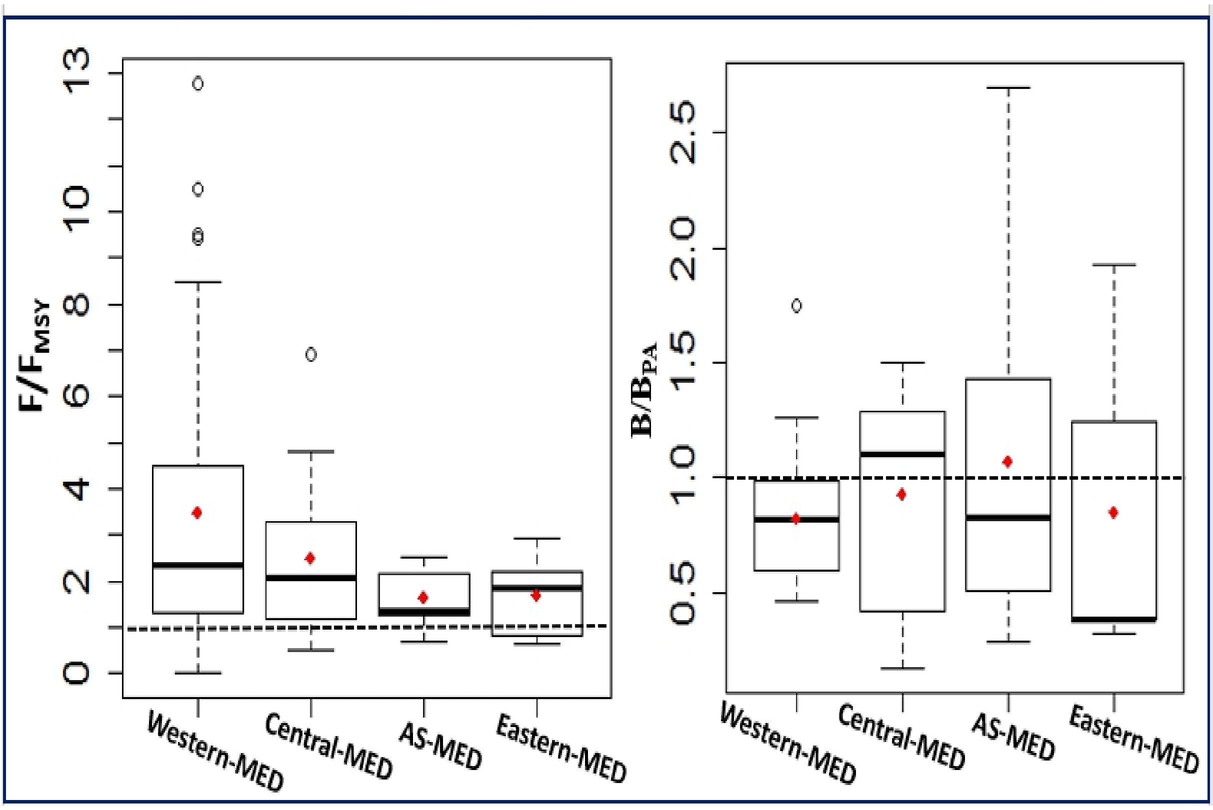


Figure 25: Status of stock size (right panel) and exploitation intensity (left panel) by Mediterranean sub-regions.

Bi-dimensional status

The simultaneous analysis of the relative fishing mortality and adult biomass (bi-dimensioned) reveals that 94% of the examined Western Mediterranean stocks and 90 % out of the reviewed Adriatic Sea stocks are in an undesirable status. Either are subjected to the overfishing status, are overfished or both the overfishing is occurring and they are overfished. However, only the minority were classified as sustainably exploited in terms of both the adult stock size and the fishing intensity applied to the stocks (Fig.22). In addition, around 87% and 75 % out of the examined stocks belonging within the Central and Eastern Mediterranean, respectively, are currently outside safe biological limits. On the other hand, the higher percentage of stocks inside safe biological limits was observed in the Eastern Mediterranean, followed by the central Mediterranean and the Adriatic Sea (Fig.26).

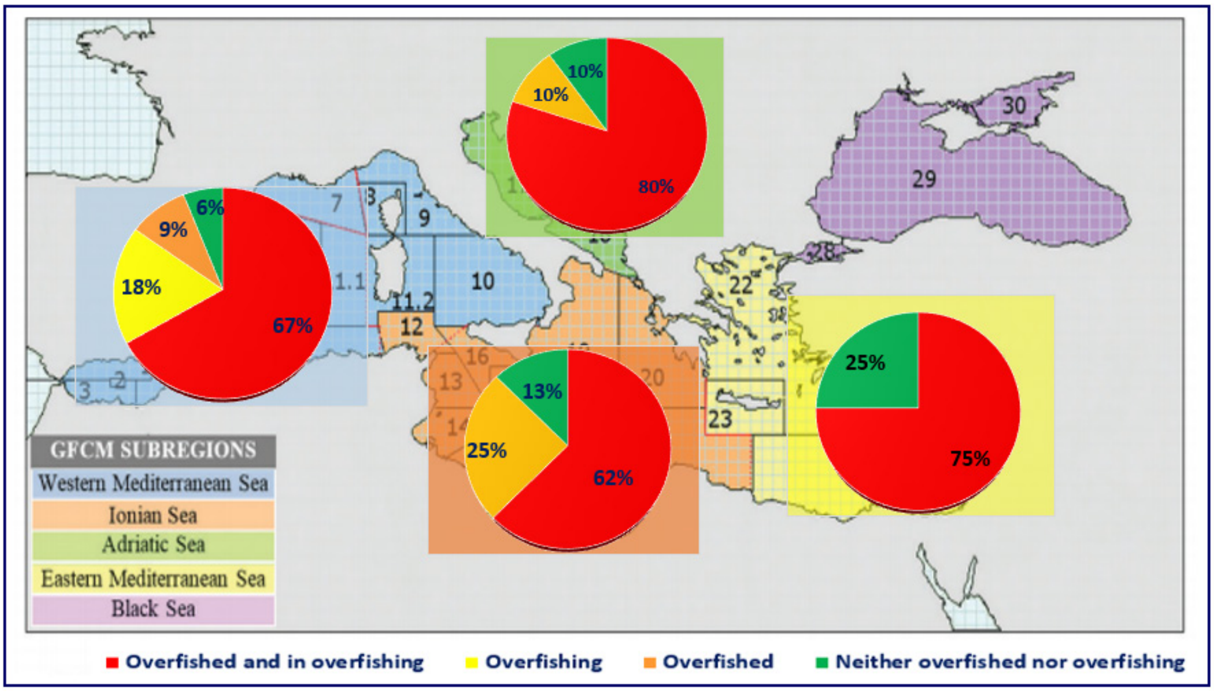


Figure 26: Bi-dimensional stock status by Mediterranean sub-region

3.2.4. Status by group of species

By species groups, the demersal fish suffer the highest overexploitation level. On average, across all Mediterranean assessed stocks, the exploitation ratio for demersal fish is about 3.7 times greater than the maximum sustainable yield, followed by the demersal crustacean that are exploited 1.8 time more than the target level. The small pelagic stocks are subjected to the lowest average fishing mortality, showing an average exploitation ratio estimated at around 1.66. On the other hand, the indicators of dispersion measures indicate that the exploitation ratios of the demersal fish have a high variability compared to the other species groups, showing the larger spread of observations (range is equal to 12.24 and IQR is equal to 3.46), the highest variance (9.46) and the greater standard deviation (3.07) (Tab.8; Fig.27- top panels).

In terms of the relative biomass ($B/B_{PA \text{ or its proxy}}$), on average the state of the small pelagic and the demersal stocks are very similar (B/B_{PA} of about 0.967 and 0.945, respectively) although, the demersal bony fish relative biomasses have a larger dispersion (Tab.8; Fig.27-top panels).

On average, the crustacean demersal stocks biomass is in a worst state with an aggregated ratio $B/B_{PA\ proxy}$ of about 0.73.

In terms of bi-dimensional status, all functional groups are in bad status given that are located in the red quadrant of Kobe plot, meaning that are overexploited and the overfishing is occurring. However, the small pelagic are in a better state compared to the other functional groups showing the lowest exploitation ratio and the highest relative biomass, in contrast, the demersal fish are in the worst status with the highest F/F_{MSY} and the lowest B/B_{PA} ratio (Fig.27- bottom panels).

The small pelagic stocks showed the highest proportion of stocks inside safe biological limits, however, the crustacean stocks were recorded the lowest one (Fig.28).

Table 8: The dispersion indicators computed for the relative biomass and exploitation ratios by species group.

	Small pelagic		Crustacean stocks		Demersal fish	
	B/B_{PA} or its proxy	F/F_{MSY}	B/B_{PA} or its proxy	F/F_{MSY}	B/B_{PA} or its proxy	F/F_{MSY}
Mean	0.967	1.66	0.73	1.8	0.945	3.76
Range (Max-Min)	1	4.68	1.11	3.62	2.53	12.24
IQR (Q3-Q2)	0.395	1.12	0.44	1.17	0.65	3.46
Variance	0.11	1.53	0.09	0.82	0.36	9.46
Standard deviation	0.33	1.24	0.30	0.90	0.60	3.07

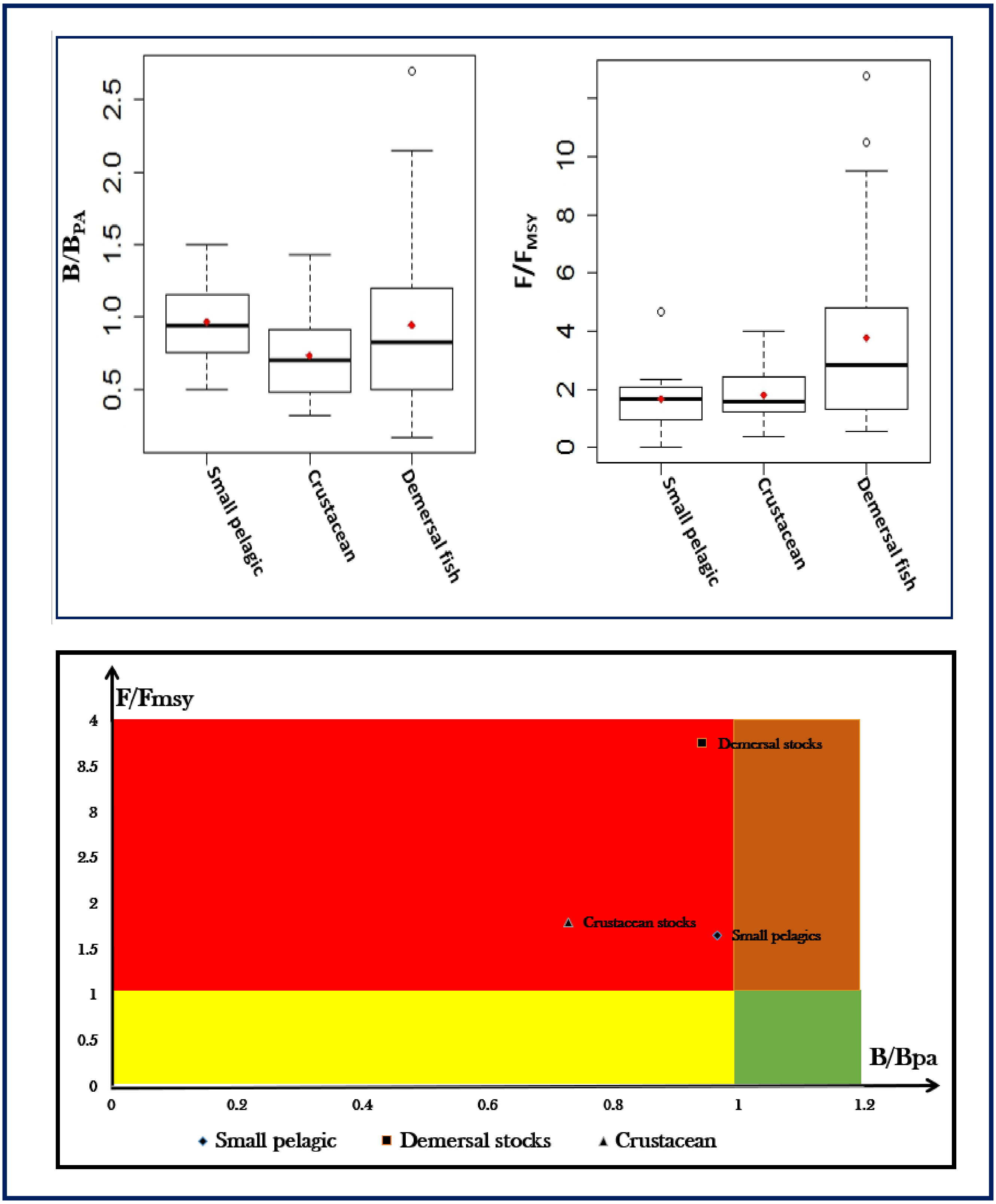


Figure 27: Distribution of the relative biomass (B/B_{PA} or its proxy) and exploitation ratio (F/F_{MSY}) by species group with red points indicate the mean (top two panels). Bi-dimensional status of the functional groups (small pelagic, demersal fish and crustacean stocks presented on Kobe plot (Bottom panel).

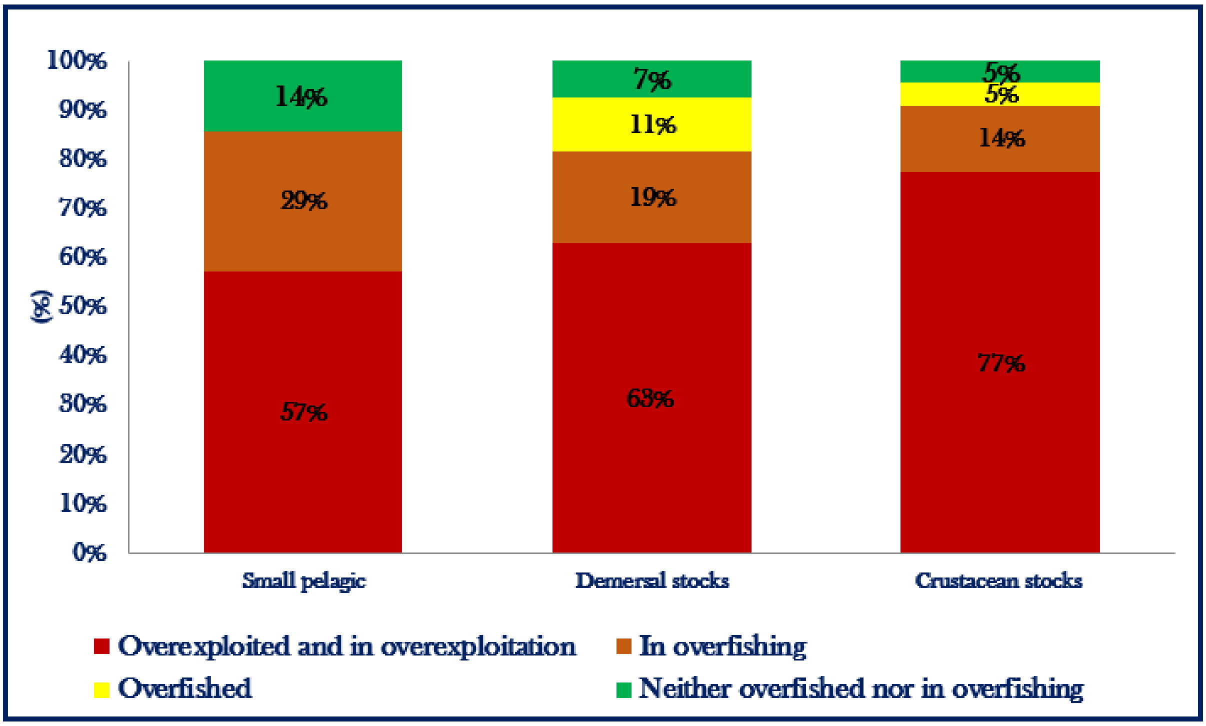


Figure 28: Status (%) of assessed stocks, for which the F in relation to F_{MSY} and B in relation to biomass reference point are available, aggregated by species groups.

3.2.5. Status by species

Overview on the exploitation status

In terms of aggregated stocks at species level, according to the average F/F_{MSY}, quasi all the Mediterranean assessed species are subjected to the overexploitation and at the forefront appear the European hake stocks with an average exploitation ratio up to 6.97. The top ten Mediterranean species that are in the highest overexploitation status are *M. merluccius, M. poutassou, L. budegassa, D. labrax, L. piscatorius, M. stebbingi , M. surmuletus, M. barbatus, G. melastomus, N. norvegicus,* successively. On the other hand, *S. smaris* has the lowest exploitation ratio, followed by the aggregated stocks of *S. solea, A. foleacea, B.boops, E. encrasicolus, A. antennatus* and *S. pilchardus*, successively (Fig.29).

Almost all boxplots are above the line $F=F_{MSY}$, except that of sardine. In effect, 50% of *S.pilchardus* stocks are harvested below the MSY. Its lowest exploitation ratio is recorded in the Gulf of Lion while the highest is observed in Northern Spain (Fig.29). The exploitation ratios distribution (Fig.29) shows some differences between species, either in terms of boxplots range, Inter-Quartile Range (IQR) and skewness pattern. The boxplots of *A. foliacea, S. mantis, A. antennatus, E.encrasicolus, P. longirostris and P.erythrinus* are relatively short compared with those of *M. merluccius, M. poutassou* and *L. budegassa* that are tall. This suggests that exploitation ratios of stocks composing the former group of species have a high level of similarity with each other, a low spread and they are more concentrated around their mean. Moreover, the four sections of the majority of Boxplots are uneven in size. This indicates that many stocks of a given species have a similar exploitation ratio at certain part of plot, but in other part stocks have more variable ratios, meaning that a variability exist inside the exploitation ratios of the examined species stocks.

About the European Hake, the boxplot indicates a high variability and spread in the set of the exploitation ratios values, given that the ratios (F/F_{MSY}) extend from a minimum of about 2.29 to a maximum of about 12.80, which they are observed in the Adriatic Sea and in the Gulf of Lions, respectively. While, most stocks have an exploitation ratio between 4.68 (lower quartile) and 8.37 (upper quartile). Similarly, 50% of stocks of Black bellied angler have an exploitation ratio range between 1.935 and 7.5, with an Inter-Quartile Range (IQR) of about 5.565 and a range estimated at around 8.94. The lowest value was recorded in the Northern Alboran Sea, whereas, the highest was observed in the Balearic Islands (Fig.29).

The stocks of Striped red mullet are averaged an exploitation ratio of about 2.876 with the majority of ratios being concentrated within the interval 2.130 (first quartile) - 3.850 (third quartile). However, the set of F/F_{MSY} spreads from a minimum of 0.880 to a maximum of 4.110 recorded in GSA 9 and GSA 15-16, respectively. In contrast to the striped red mullet, the red mullet exploitation ratios have a positive skew with the maximum of stocks have an F/F_{MSY} upper than median (1.3). In effect, out of 13 examined stocks, 3 (23%) are exploited at or below the MSY. Its lowest ratio of F/F_{MSY} is observed in Northern Adriatic Sea, while the highest one is recorded in Sardinia.

In terms of individual stocks, the vast majority (86 %) of examined stocks are exploited above the level that can produce the maximum sustainable yield. However, the minority of stocks are exploited in accordance with MSY level, namely the stocks of sardine in Gulf of Lions, blue and red shrimps in the Ligurian and Nord Tirrenian Sea, picarel in Cyprus, Norway lobster in strait of Sicily (GSA 15-16), red mullet in Cyprus, stripped red mullet in the Ligurian and Nord Tirrenian Sea, sardine in Alboran sea, and red shrimp in combined GSA 9-11, which are sequentially arranged from the largest to the smallest observed exploitation rate. While, the stock of red mullet in South and Central Tyrrherian Sea is classified as fully exploited given that is exploited at the sustainable level ($F= F_{MSY}$).

The hake in Gulf of Lions is the stock that is subjected to the highest overexploitation being exploited more than 12 times greater than the fishing mortality level that is believed to ensure the sustainable exploitation ($F_{0.1}$). It is followed by the black-bellied angler in Balearic Island and the blue whiting in the Northern Spain with an exploited ratio estimated at about 10.5 and 9.5, respectively. Then appear the hake stocks in Sardinia, in Alboran Sea and in Corsica with a fishing mortality exceed more than 8 times the rational exploited level. It seems that the red mullet stocks in Sardinia and in Balearic Island are heavily exploited too with ratio estimated at around 8 and 7, respectively. The stocks of black-bellied angler in northern Spain and the stock of hake in the strait of Sicily are exploited around six times more than the F_{MSY} proxy.

Subsequently, the stocks that are exploited 5 to 3 times more than the level than can ensure the stocks sustainability are sardine in GSA 10, hake in GSA 9, stripped red mullet in combined GSAs 15-16, Norway lobster in GSA 6, stripped red mullet in combined GSAs 13-14, Norway lobster in GSA 5, red mullet in combined GSAs 1-4, stripped red mullet in GSA 1, red mullet in GSA 7, anglerfish in combined GSAs 1-5-6-7 and European seabass in GSA 7.

Then, appears stocks having an F/F_{MSY} ranged from three to 1.66. those stocks are deep water rose shrimp in northern Spain, giant Red Shrimp in strait of Sicily, blackmouth catshark in southern Adriatic Sea, common Pandora in Sicily and Malta, deep water rose shrimp in Alboran sea, spottail mantis squillid in Ligurian and Nord Tirrenian Sea, European anchovy in Northern Alboran sea, hake in Adriatic sea, red shrimp in northern Spain, European anchovy in Ligurian and Nord Tirrenian Sea, sardine in Alboran sea, black-bellied anglerfish in Sicily and Malta, Norway lobster in Sardinia, gilthead seabream in Gulf of Lions, red shrimp in Northern Alboran sea, European anchovy in Adriatic sea, Norway lobster in Ligurian and Nord Tirrenian Sea, blackspot seabream in Alboran sea and horse mackerel in combined GSAs 9-11 (Tab. 9).

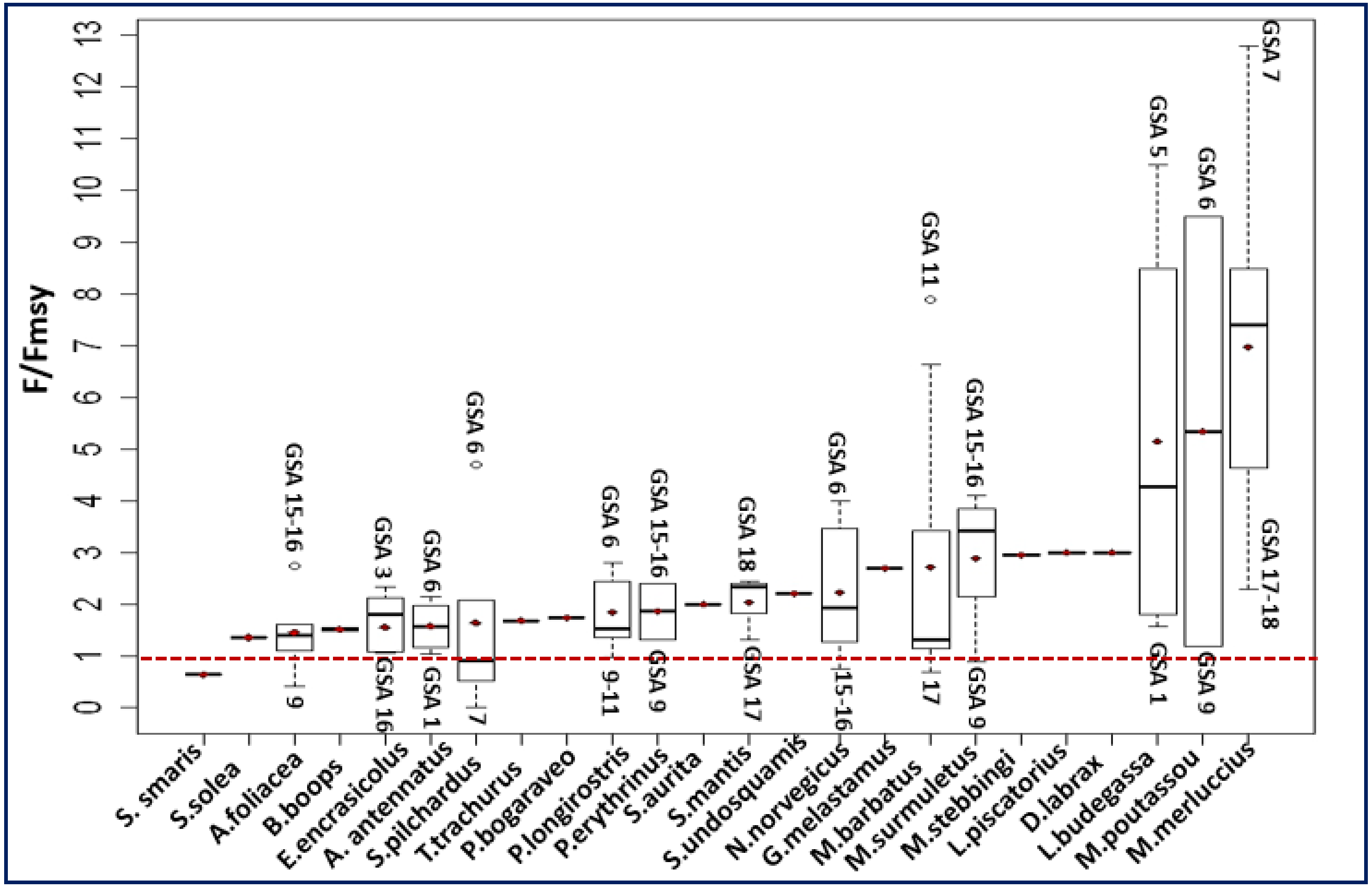


Figure 29: Boxplot represents the five-number summary (min, max, first, second (median) and third quartiles) of exploitation ratios grouped by species, the GSAs where the minimum and maximum values are observed were added (the dotted red line indicates the reference value ($F=F_{MSY}$)). The red dots indicate the arithmetic mean.

Table 9: Exploitation ratio estimated (F/F_{MSY}) for latest validated assessments (for which a F_{MSY} proxy is available) by the SAC of GFCM and STECF of Commission European. A grad red-orange-yellow was used to class the exploitation ratio from the more (dark red) to the less overexploitation status. The ratio $F/F_{MSY} \leq 1$ are colored in green.

Species	Western Mediterranean									Central Mediterranean						Adriatic sea		Eastern MED	
	1	3	4	5	6	7	9	10	11	12	13	14	15	16	19	17	18	25	26
E.encrasicolus	2.33				1.08		1.48							1.05		1.79	1.79		
S. pilchardus	0.90	0.90			4.69	0.01								0.53		2.07	2.07		
M. merluccius	8.50	8.50		7.88	8.00	12.80	4.50	4.63	9.41	6.92	6.92	6.92	6.92	6.92	4.83	2.29	2.29		
P. longirostris	2.38	2.38	2.38	1.24	2.80		0.96	0.96	0.96	1.46	1.46	1.46	1.46	1.46	1.53	2.51	2.51		
M. barbatus	3.42	3.42	3.42	6.64	1.24	3.23	1.13	1.00	7.90		3.52	3.52	1.24	1.24	3.08	1.30	0.70	0.81	
P.bogaraveo	1.73	1.73																	
S. endosquamis																			2.20
A. foliacea							0.41	1.40	1.60				2.73	2.73	1.10		1.10		
A. antennatus	1.80			1.03	2.15		1.31												
B. boops		1.48																1.54	
G. melastomus							2.69												
L. budegassa	1.56			10.5	6.5								2.06	2.06					
M. stebbingi																			2.94
M. surmuletus	3.41			3.85			0.88						4.11	4.11				2.13	2.13
N. norvegicus				3.46	4.00		1.79		2.05				0.75	0.75		1.26	1.26		
P. erythrinus							1.31						2.40	2.40					
S. solea																1.35			
S. smaris																		0.64	
S. mantis							2.34									1.31	2.44		
T. trachurus							1.68	1.68	1.68										
L. piscatorius	3.00			3.00	3.00	3.00													
S. aurata						2.00													
M. poutassou					9.50		1.19												
D. labrax						3.00													

Overview on the stock size status

The combined relative biomass (mean B/B_{PA}) by species indicates that, successively, the five top most overexploited Mediterranean species are *M. stebbingi, S. undosquamis, S. mantis, N. norvegicus, S. solea* and *M. surmuletus* with an average relative biomass estimated at about 0.32, 0.38, 0.51, 0.62, 0.65 and 0.7, respectively. However, on average, *S. smaris, M. barbatus* and *S. pilchardus* seem to be in a best state compared to the other species. Indeed, they were averaged a biomass ratio of about 1.26, 1.24 and 1.2 respectively (Fig.30). On the other hand, the red mullet relative biomass shows the highest variability across the different stocks compared to all the other examined species, given that the ratios $B/B_{PA\ (\text{or its proxy})}$ are spread from a very low value of about 0.17 to a maximum of about 2.7 observed in strait of Sicily and Adriatic Sea, respectively. Moreover, around 45% of those stocks have a biomass below the reference point. On the contrary, the relative biomass of *N. norvegicus* stocks is the most concentrated around the median with 50% of relative biomass range between 0.51 and 0.73. The sardine stocks seem to be in a better state compared with the anchovy stocks, given that 66% of sardine stocks relative biomass is above the red dotted line ($B/B_{PA\ \text{or its proxy}}$ =1), while the majority (75%) of anchovy biomass ratio is below 1 (Fig.30).

In terms of individual stocks, among the examined stocks (n=57) for which a spawning biomass ratio was estimated 39 stocks have a biomass below the threshold reference point, meaning that they are overexploited, hence, the reproductive capacity is in a risk to be impaired (Tab.10).

In fact, the biomass with respect to the reference point (B_{PA}) indicates that the red mullet in combined GSAs 15-16 is in a very worrying state given that it was reached the lowest biomass ratio estimated at about 0.17. It followed by stocks of European hake in the Adriatic Sea, giant red shrimp in the GSAs 15-16, Norway lobster in Adriatic Sea, deep-water rose shrimp in Strait of Sicily, hake in gulf of Lions, red mullet in the Ligurian sea and northern Tyrrherian sea and stocks of giant red shrimp in South and central Tyrrherian sea, which they scored a ratio lower than 0.5 each one (Tab.10).

It was revealed that 7 out of the 39 overexploited stocks are so close to reach the green area, those stocks are deep-water rose shrimp in GSA 5, European hake in GSA10, red mullet in GSA 19, anchovy in GSA 17-18, deep-water rose shrimp in GSA 17-18 and stripped red mullet and European hale in GSA 5, successively.

In contrast, some stocks have currently a biomass above the B_{PA} but they are so close to drop below the target level, namely stocks of deep water rose shrimp in Northern Spain, in combined GSAs 9-11 and in Northern Alboran Sea as well as the stocks of red mullet in the Balearic Island and stock of the sardine in Northern Spain (Tab.10).

Figure 30: Distribution of relative biomass ($B<B_{PA}$) of examined stocks grouped by species using Boxplot (a), the GSAs where the minimum and the maximum of B/B_{PA} was observed value are added to the boxplots (the red dotted line separates the good from the bad status ($B=B_{PA}$)). The red dots indicate the arithmetic mean.

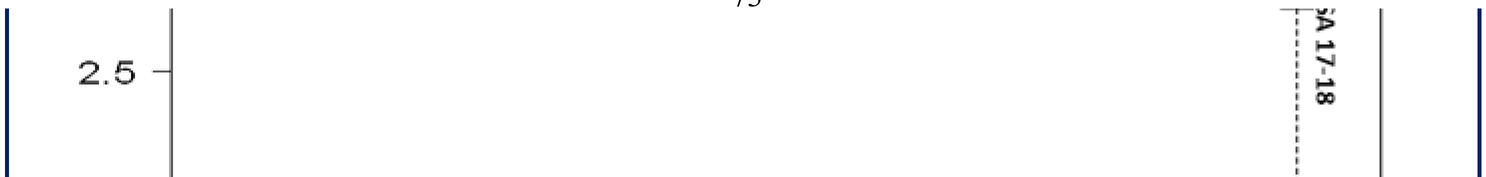


Table 10: Spawning biomass ratio for latest validated assessments (for which a B_{PA} was available or estimated.) by the SAC of GFCM and STECF of Commission European. A grad red-orange-yellow was used to class the relative biomass from the more (dark red) to the less overexploited status. The ratio $B/B_{PA} \geq 1$ are colored in green.

Tot = 57 stocks	*Western Mediterranean*									*Central Mediterranean*						*Adriatic Sea*		*Western-MED*	
Species	*1*	*3*	*4*	*5*	*6*	*7*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*19*	*17*	*18*	*25*	*26*
E.encrasicolus					0.79	0.50								1.25		0.94	0.94		
S. pilchardus					1.06									1.50		0.73	0.73		
M. merluccius	0.52	0.52		0.91	0.61	0.46	0.47	0.97	0.5	1.2723	1.27226	1.272	1.272256		1.29	0.29	0.29		
P. longirostris	1.03			0.98	1.00		1.00	1.00		0.42	0.42	0.42	0.42	0.42	0.67	0.92	0.92		
M. barbatus	0.59	0.59	0.59	1.03	1.24	1.75	0.48	0.85					0.17	0.17	0.96	2.70	2.15	1.93	
S. endosquamis																			0.38
A. foliacea							0.76	0.48	0.88				0.32	0.32	1.43		1.43		
A. antennatus	0.85			0.66	1.26		0.77												
M. stebbingi																			0.32
M. surmuletus	0.72			0.91			0.80												0.38
N. norvegicus							0.83		0.64							0.38	0.38		
S. solea																0.65			
S. smaris																		1.24	
S. mantis																0.51	0.51		

Bi-dimensional status.

The best part (n=38) of the represented stocks on Kobe plot are in the red quadrant accounting for about 69% of total reviewed stocks, which indicates that they are overexploited and the overexploitation is occurring. The level of this undesirable status differs from one stock to another. Some stocks are in the risk of the depletion given that the stock biomass is so low like the stock of red mullet of strait of Sicily, while the hake of Gulf of Lions is the stock that is subjected to the highest overexploitation level in Mediterranean Sea.

Out of the 16 stocks that have an estimated relative biomass ($B/B_{PA \text{ or its proxy}}$) above one, five stocks are located within the green quadrant indicating that are in a healthy state in terms of both stock size and fishing mortality. Those stocks are namely, red mullet in GSA 18 and in GSA 25, sardine and anchovy in GSA 16 and stocks of picarel in GSA 25. However, 11 stocks are situated in the orange quadrant, which significates that the fishing mortality applied to those stocks is above the level that can produce the maximum sustainable yield, among them two stocks (anchovy in GSA16 and giant red shrimp in GSA 19) are subjected to a very low overfishing (F/F_{MSY} is equal to 1.05 and 1.10). In contrast, other stocks are either in the intersection with the red area (deep water rose shrimp in GSA 6) or so close to it, especially the case of the stocks of red mullet in the Balearic Island and the stock of sardine in GSA 6 (Fig.31).

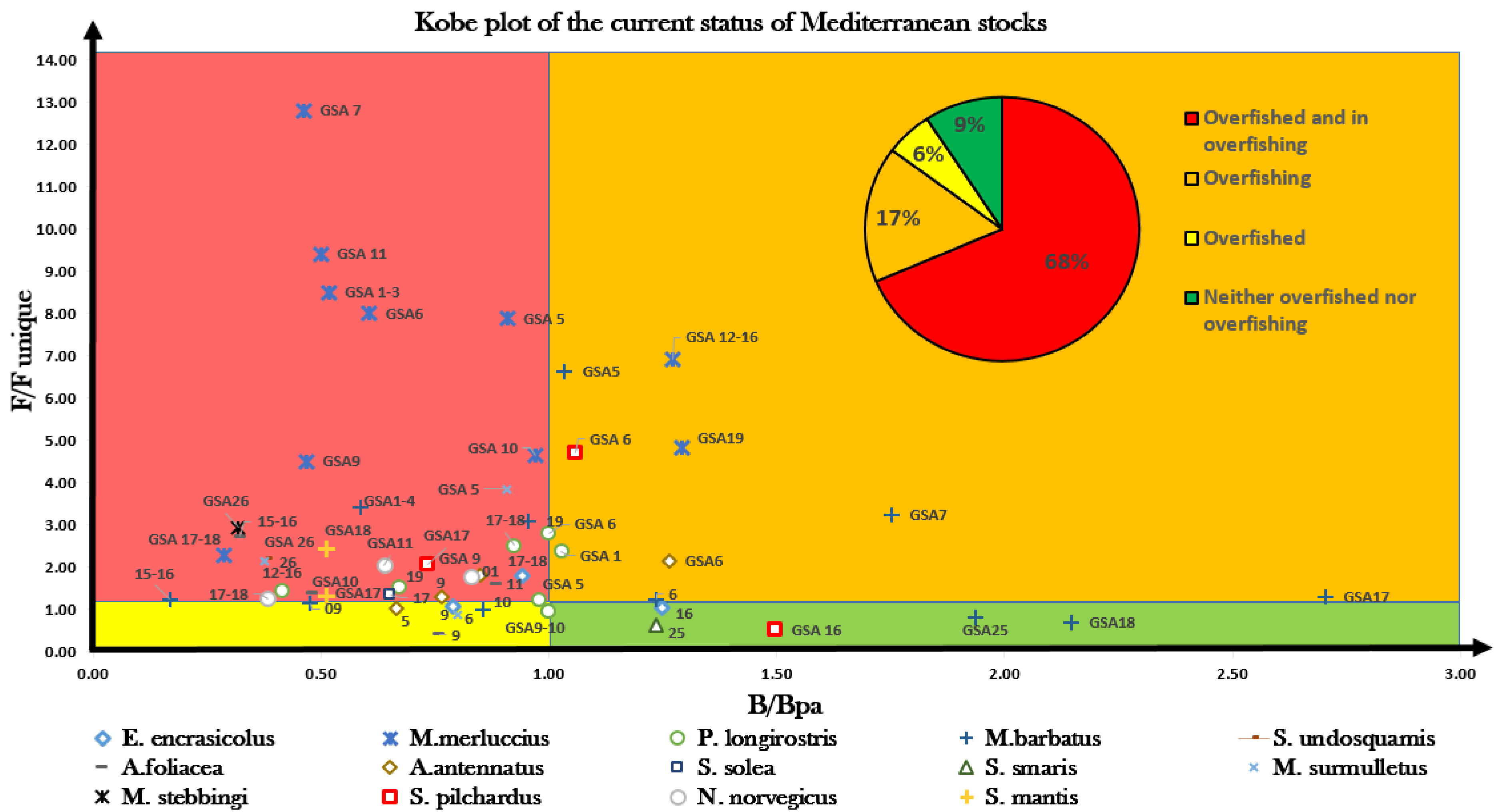


Figure 31: Kobe plot of the current stock status of Mediterranean stocks for which both ratio of biomass and exploitation were estimated. Pie chart represents the percentage of each stock status to total examined stocks.

3.3. Temporal trend

Trend on indicator of stock status

Overall, the regional relative spawning biomass is experiencing a significant (R^2 = 0.75) downward trend, and since 2001 it dropped below 1 indicating that on average the SSB was below the sustainable level. In contrast, the relative fishing mortality follows an upward trend with clear fluctuations. From 1980 onwards, the fishing mortality exceed the level that can produce the maximum sustainable yield. While, no evident trend was observed for the recruitment index, which showed big fluctuations over the studied period with sequence of periods when the recruitment was located above and below the long-term average mean (Fig. 32).

In the beginning of the time series, the SSB ratio (SSB/SSB_{PA}) was increased from about 1.8 in 1975 to 2.7 in 1978. Afterwards, a strong continuous decrease was observed over the period 1979-1987 at a rate of about -50%. Since then, the biomass tracks a decreasing trend with observed fluctuations; from 1987 to 2000, on average the relative biomass has declined with a rate of about -25%. In the following years, the relative spawning biomass remains overall stable in an average value of about 0.87 except in 2006 when a pic of about one was recorded. At the end of the time series (2013-2015) a recovery was observed when the biomass showed a slight increase with an average percentage at around 4% (Fig.33).

By species, the rate SSB/SSB_{PA} for the Crustaceans stocks decreases significantly over the examined period (P-value well below 0.05) with an R squared being equal to 0.67. The small pelagic stocks adult biomass ratio decreases more strongly and significantly, as the R squared is about 0.76 and P-value equal to 1.089e-13. The decreasing trend of demersal bony fish relative adult biomass over the studied period is less significant (R squared equal 0.3642, P-value equal 9.77e-05) than the other species group. On the contrary, from 2008 onwards it is increasing considerably and significantly, given that during that period the slope of the linear regression is positive, the R squared is about 0.833 and the p-value is equal to 0.001556 (Fig.35-left panel).

The further breakdown of the combined ratio shows that the relative adult biomass of red mullet *(M. barbatus)* stocks are increasing steadily and significantly (R squared = 0.87) from 2008 onwards. However, the ratio SSB/SSB_{PA} of Norway lobster (*N. norvegicus*), hake (*M. merluccius*), and red shrimp *(P. longirostris)* stocks drop considerably from 2009, 2003 and 2010, respectively. Whereas, from 2005 onwards, the spawning biomass of anchovy stocks is around its threshold biomass reference point (SSB_{PA}), on average their combined relative adult biomass is equal to 1.01. The spawning biomass of sardine stock in the Adriatic Sea is improving slightly over the last ten years (Fig.35-right panel).

The recruitment index shows strong fluctuations over the studied period, in fact the regional recruitment was above the long-term average mean during the period 1980-1990, then it dropped below it from 1992 to 2003. During the following three years, the recruitment index remained stable around its long-term mean (R/men R=1). Then, the estimated recruitment dropped down its long-term mean. In the terminal years (2014-2015), a slight increase is observed at an average rate of about 8.5 % (Fig.33).

Concerning the temporal trend on the fishing mortality relative to F_{MSY}, the exploitation was increased spectacularly from 0.30 in 1979 to 2.6 in 1982, in the main time the SSB started to track a decreasing trend. After this period, the exploitation ratio fluctuates strongly but with an increasing overall trend. In fact, the combined F/F_{MSY} was decreased from a value of about 2.65 in 1982 to a value of about 1.40 in 1990, afterwards the fishing mortality was increased to reach a value of about 3 (nearly the double) in 2003. Then, it was going down continuously until 2006 when a slight gradual increase was observed that continued until 2011. Soon the F was return to increase until the terminal year when a decrease was recorded (Fig.33).

The further breakdown of the aggregated exploitation ratio (F/F_{MSY}) by species group shows that from the beginning of the time series the demersal species, notably the bony fish stocks, are in a heavy overexploitation, followed by the crustacean stocks that are started experiencing the overexploitation from 1995. While, the combined exploitation ratio for small pelagic stocks indicates that this group was in a rational exploitation until 2001 when for the first time the combined fishing mortality exceeded the fishing mortality that can produce the maximum sustainable level (Fig. 34-left).

Moreover, the combined exploitation ratio by species indicates that from 2004 all the assessed stocks combined by species are in overexploitation status. The Hake stocks are in the worst state being exploited on average around six times above the MSY over all the examined period. In fact, those stocks were experiencing a spectacular overexploitation in the beginning of the period (1980-1982) with an average fishing mortality exceed 10 times the $F_{MSY.}$ A considerable decrease was observed during the period between 1983 and 1990, when the exploitation ratio was decreased from a value of about 11 to a value of three. Afterwards, an apparent fluctuation was shown with a succession of periods of decline and rise, on average F was four times above F_{MSY} for the period 1990-2000, while it is estimated to be 5 times and 6.5 times above F_{MSY} during the period 2000-2010 and 2010-2015, respectively. In contrast, sardine stocks were in a better state, being exploited below the maximum sustainable yield until 2004 when the overfishing status was started occurring. On average, from 2004 onwards, these stocks are exploited 2 times above the sustainable level with an apparent increasing trend.

On the other hand, the red mullet stocks were shown an improvement as the exploitation rate follows a significant decreasing trend (R-squared equal 0.97 and P-value estimated at 1.234e-08) from 2005 onwards, specifically the case of the stocks of red mullet in GSA 17, GSA18 and in GSA 25. However, the combined exploitation ratio for anchovy stocks follows a significant (R-squared equal 0.79) upward trend continued until 2002. Fortunately, it was decreased strongly ($R^2 = 0.87$ and P-value = 0.001335) over the period 2002-2008 to stabilize afterwards (Fig. 34-right).

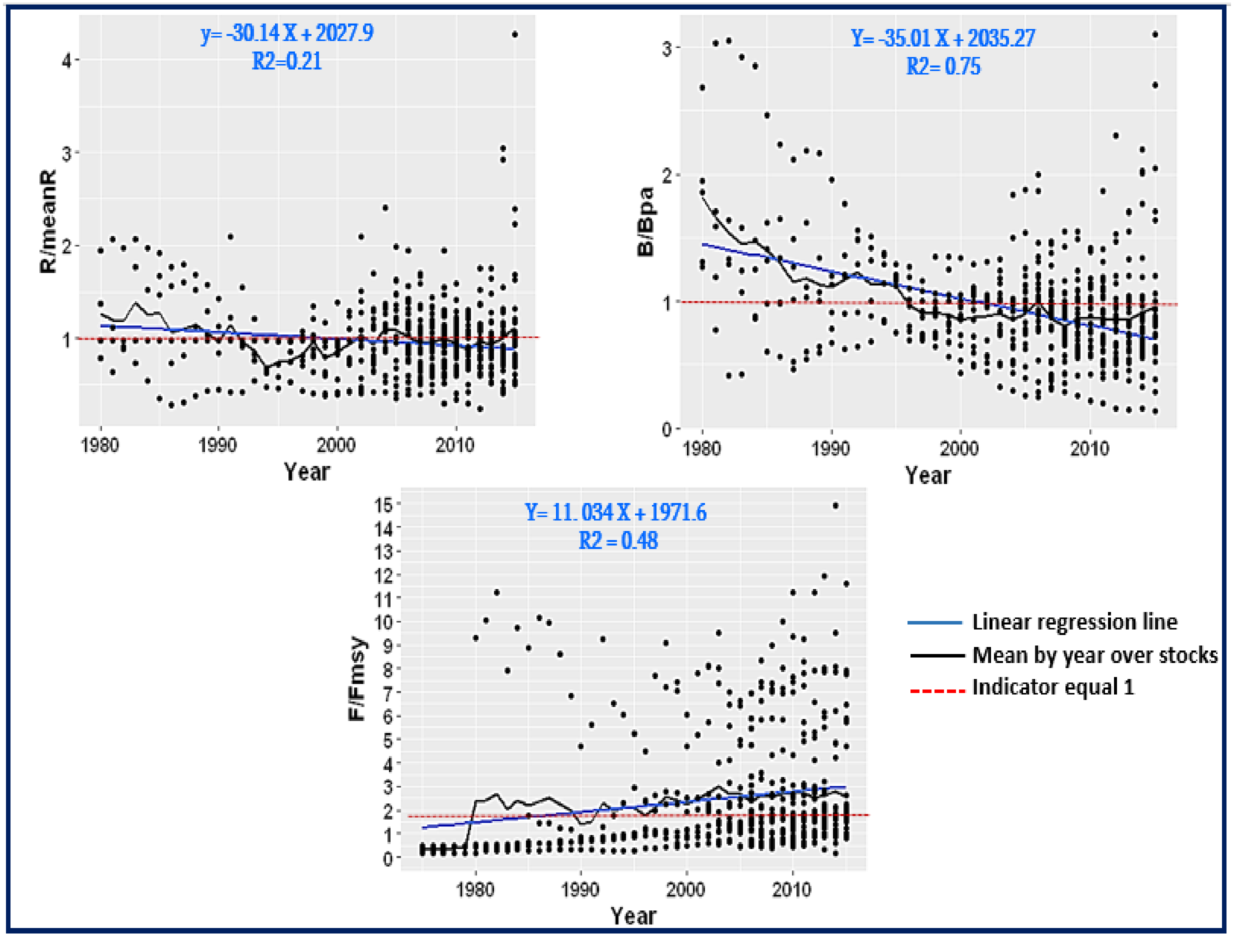


Figure 32: Regional temporal trend in the recruitment index (R/mean R) (top left panel), spawning biomass relative to the threshold reference point (B/B_{PA}) (top panel right) and the fishing mortality relative to F_{MSY} by year (bottom panel). The black line reflects the mean values by year across all included stocks (black dots points) and the blue line is the linear regression line. The red dotted line indicates the limit between the desirable and undesirable status.

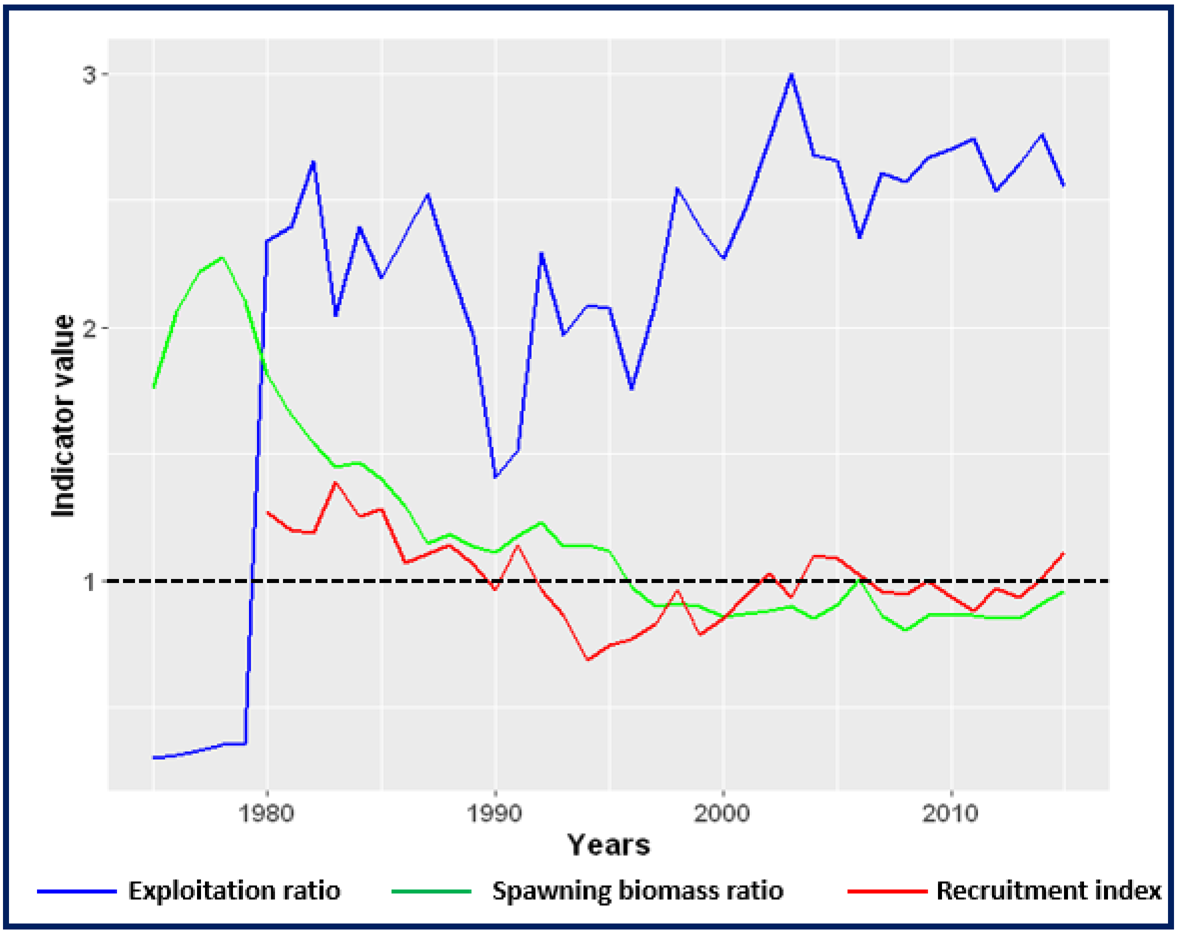


Figure 33: Comparison between the combined indicators of exploitation (blue line), adult biomass (green line) and recruitment (red line) in relation to their associated reference point. The dotted black line indicates the reference value (indicator equal reference point).

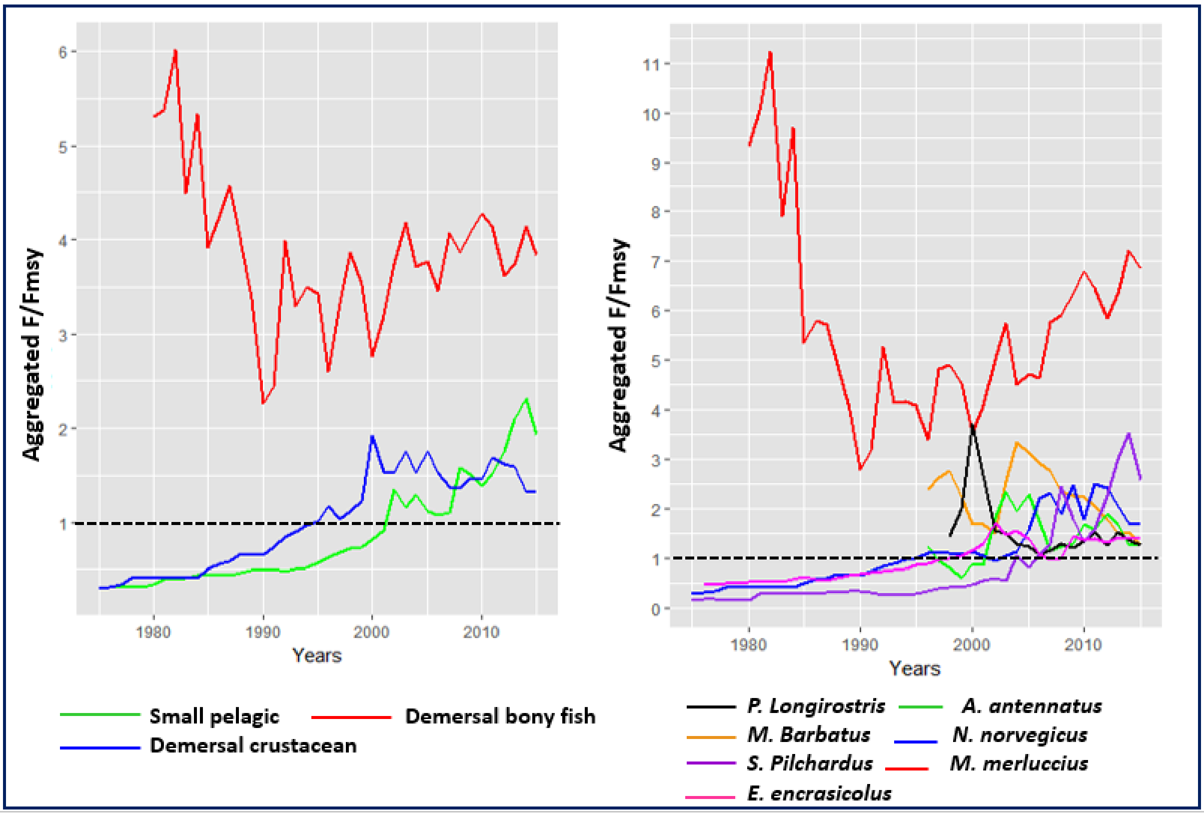


Figure 34: Temporal development of combined exploitation ratio (F/F_{MSY}) of Mediterranean stocks combined at group of species (left panel) and species level (right panel). The dotted black line indicates the reference value (F/F_{MSY}=1).

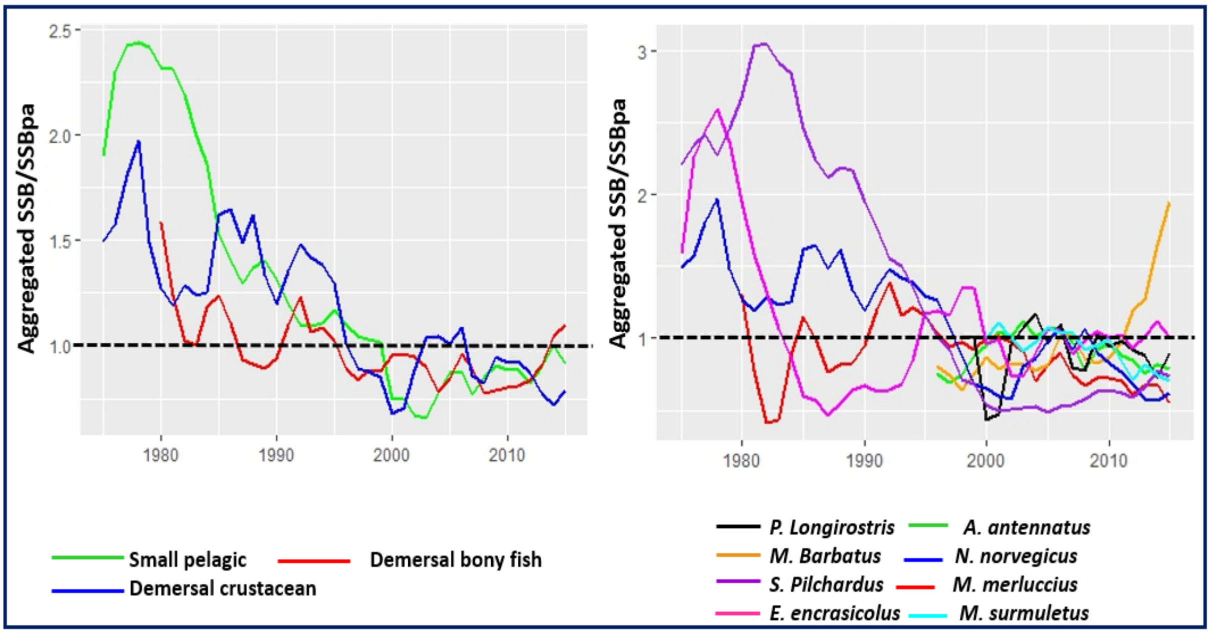


Figure 35: Temporal development of combined relative spawning biomass (SSB/SSB_{PA}) of Mediterranean stocks combined at group of species (left panel) and species level (right panel). The dotted black line indicates the reference value (SSB/SSB_{PA} =1).

Evolution of Mediterranean stock status as defined in SAC and STECF annual reports

In the Mediterranean Sea, the proportion of stocks assessed as outside safe biological limits (either overexploited, depleted, ecologically unbalanced or in low biomass) dominates both the small pelagic and demersal assessed stocks and that through the examined period (Fig. 36-2 and 3).

The temporal evolution of status of Mediterranean stock indicate that the percentage of deteriorated stocks raised linearly and significantly from 40 % in 2006 to 98 % in 2011. However, at the same time, an apparent declining trend in the proportion of stocks with no farther room of expansion was shown. In 2012, the situation seemed to be improved when the stocks assessed as deteriorated was declined, whereas, the proportion of healthy stocks was slightly raised which returned to decrease afterwards taking the place to the number of stocks outside safe biological limits to increase again. On the other hand, the number of validated assessments was dropped in 2012 followed by a continuous increase. An improvement in stock status is apparent in the recent assessments (2015) but it need to be confirmed in the coming years (Fig. 36-2).

The further breakdown of the status of Mediterranean stocks by group of species (demersal versus small pelagic) shows that the demersal stock status follows the same trend as the combined species status evolution (Fig. 36-3 left). While, the evolution of proportion of small pelagic stock assessed as below, at and above safe biological limits present more strong fluctuations but keeping more or less the same pattern of stock status. In fact, a strong increase in the contribution of stocks outside safe biological limits to the total was observed which passed from 28% in the start of the examined period to 90% in 2010 accompanied with a decline in the proportion of stocks at safe biological limits. In 2012, the stock status trend was reversed, i.e., the proportion of stock at and below safe biological limits was increased, while the stocks beyond safe biological limits was declined. This status did not stay long, trend was reversed again in the next year, with a strong increase in the proportion of undesirable stock status and decrease in the proportion of desirable stock status (Fig.36-3 right).

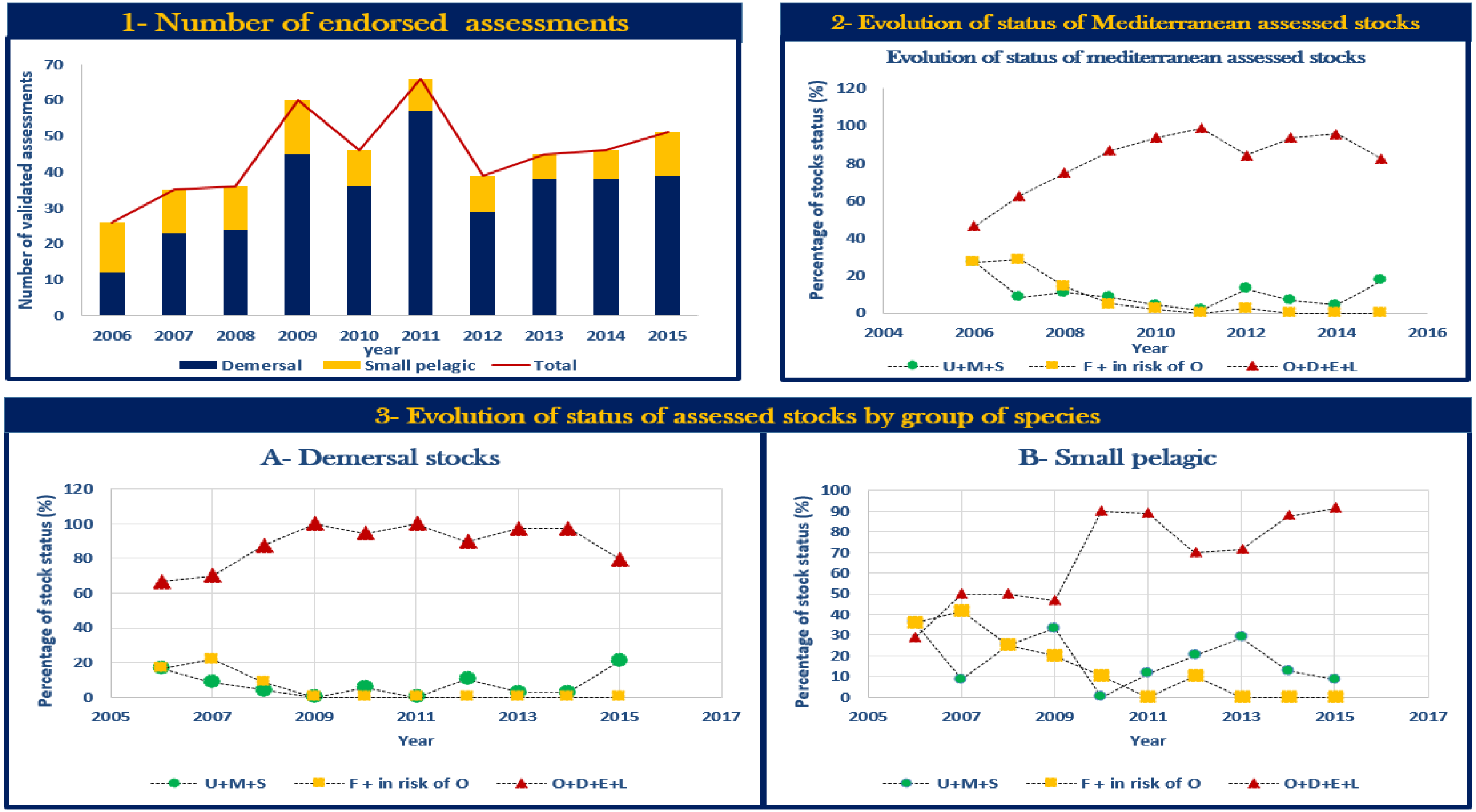


Figure 36: Evolution of total number of endorsed assessments by refernce year(reference year of the assessment) by both STECF of EC and SAC of GFCM (1), status of mediterranean assessed stocks per yer combined (2) and per species group (3). U : under exploited , M : Moderatly exploited, S : sustanbly exploited , F : Fully exploited, In risk of O :In risk of Overexploitation , O : Overexploited , D : Deplated , E : Ecologically unbalanced, L : Low biomass level.

3.4. Status of selected stocks

3.4.1. Adriatic Sea

3.4.1.1. Small pelagic

A. Sardine

Comparative analysis

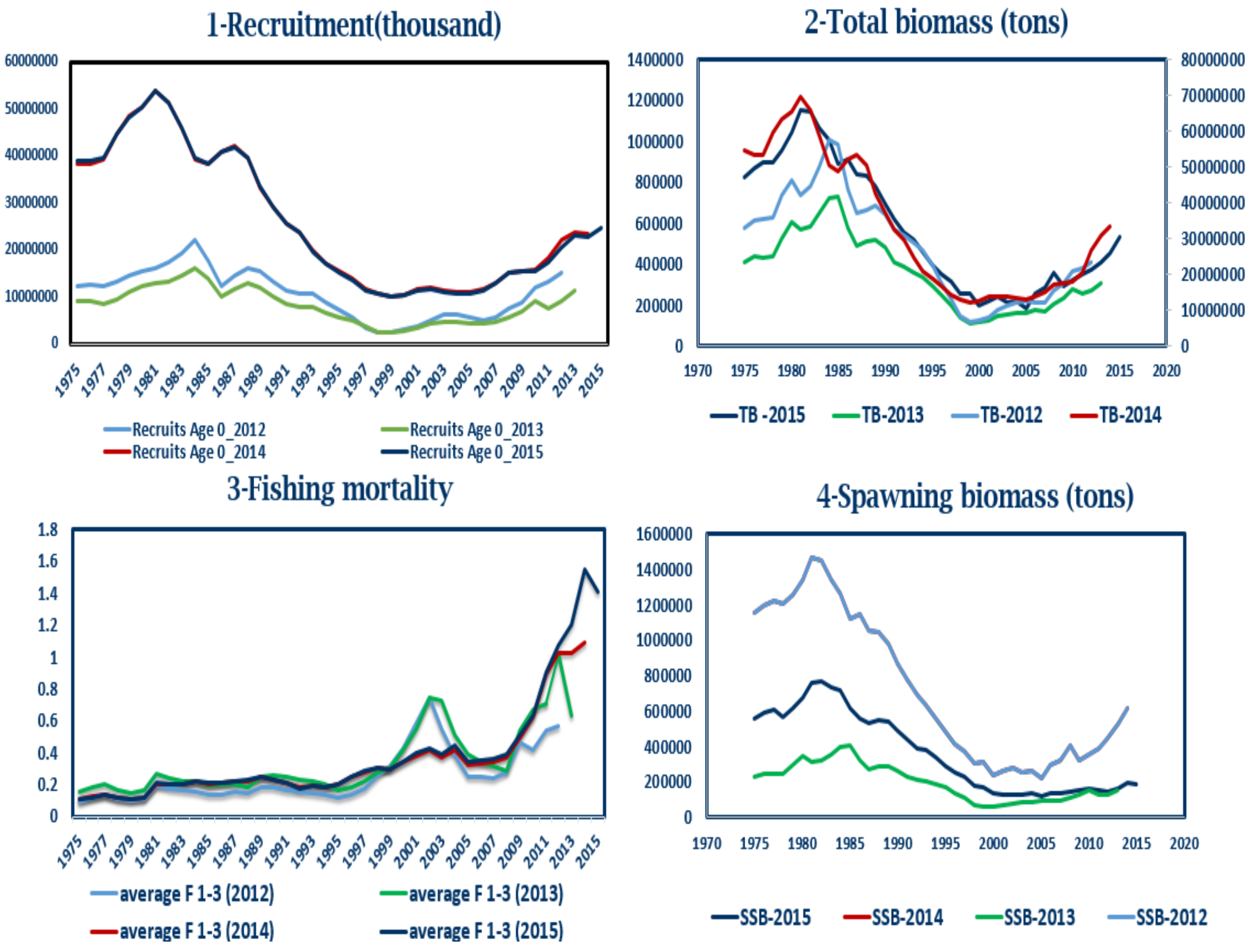
The stock of sardine in the Adriatic Sea was assessed from 2012 through the SAM model which allowed estimate the time series of recruitment (R), Total Biomass (TB), Spawning Stock Biomass (SSB) and Fishing mortality (F).

Overall, the time series of estimates of recruitment produced by the successive assessments tend to follow the same overall trend (Fig.37). However, the last assessments are quite similar and they overlap, while, the time series from the previous assessments (2012 and 2013) do not overlap. It appears that the last two assessments are consistent and no retrospective pattern is observed, while, they are farther from the previous estimates, which they follow exactly the same trend.

About the total biomass, the 2012 and 2013 assessments produced a TB time series that follow the same overall trend without a complete overlap. Although the 2014 assessment is overestimated (the secondary axis) compared with the other examined time series (the principle axis) it follows the same trend as the TB time series estimated by last endorsed assessment (Fig. 37-2).

The spawning biomass time series from 2012 assessment overlap with that resulting from 2014 assessment, while the fishing mortality time series produced by the last assessment follow the overall trend of time series estimated by 2013 assessment (Fig.37-4).

Until the 90s, estimates of fishing mortality time series were stable and track the same trend. Since then, the time series from 2012 and 2013 assessments diverged from the other assessments and follow a specific trend marked by a continuous upward. Those last two F time series estimates showed a strong consistence until 2013 where a clear retrospective pattern was observed (Fig.37-3).



Indicator time series from one assessment and from last assessment

The comparison between indicator time series from the last validated assessment (2015) and that built from the annual reported estimates revealed that the fishing mortality time series track the same upward trend. While, some inconsistency is shown in the spawning biomass and recruitment time series where the estimated value of the spawning biomass and that of the recruitment estimates are overestimated and underestimated in 2014 and 2013, respectively (Fig.38).

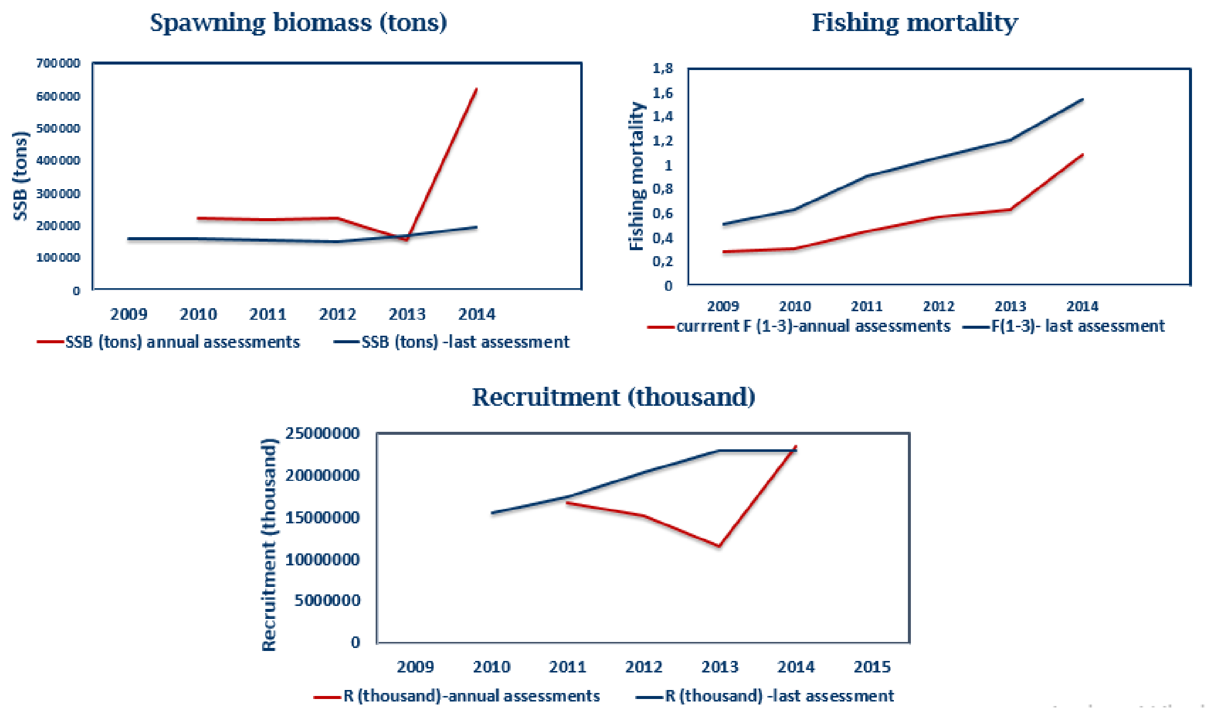


Figure 38: Comparison of time series indictors of stock status from last assessment (2015) and from annual assessment of the Adriatic sardine.

Overview on the stock status

Given the inconsistency between the successive assessments and between time series from last assessment and those resulted from the collect of annul estimates of current values, the break down analysis of stock status will be based on the last validated assessment.

Status of exploitation

Overall, estimates of fishing mortality ratio for ages 1-3 have an upwards trend over the studied period. From 1975 to 2010, the exploitation ratio (F/F_{UNIQUE}) was below 1 and hence the stock trajectory was situated in the green quadrant, indicating that the stock of sardine in the Adriatic Sea was exploited sustainably. From that time, the stock started experiencing the overfishing status with an exploitation ratio is well above 1, increasing continuously till reaching the highest observed value in 2014 that up to 2 times the level that can ensure the stock sustainability (Fig.39). In terms of overfishing intensity, in 2011 the fishing mortality ratio was under 1.33, indicating that a low overfishing is applied to the examined stock, afterward the level was increased constantly, which become intermediate during the period 2011-2013. Since then, a high overfishing level is occurring (Fig 39).

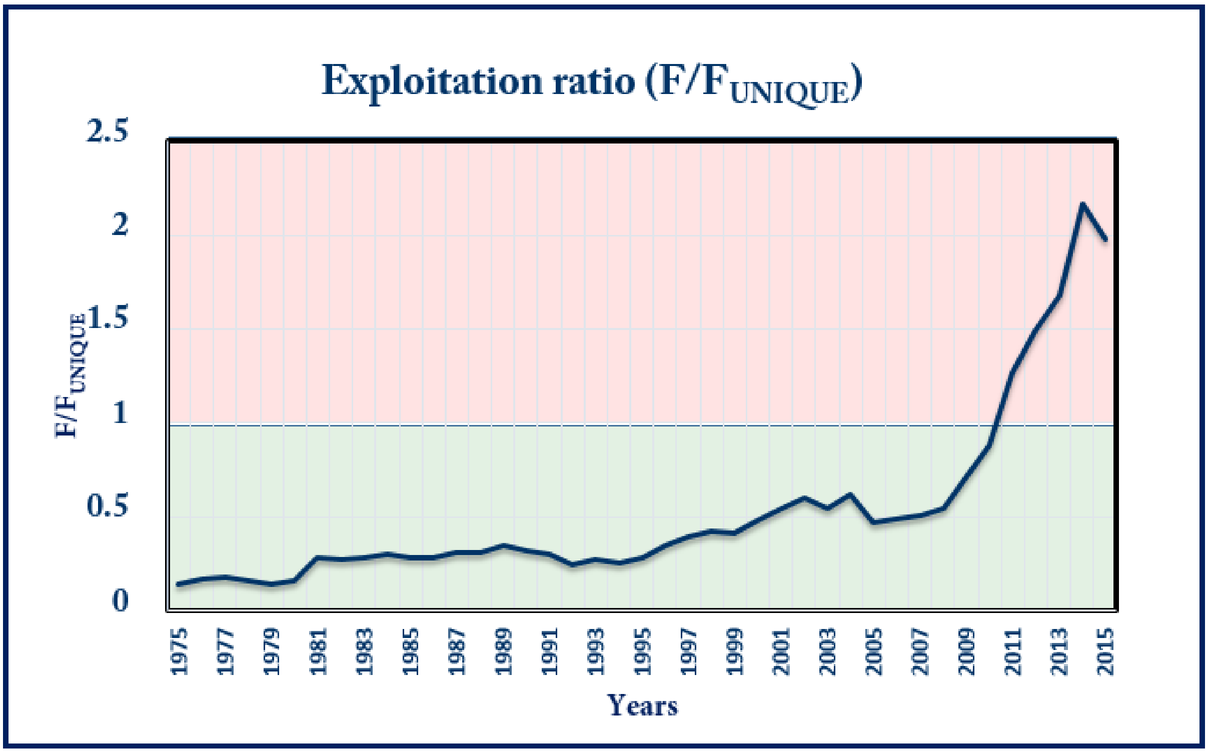


Figure 39: Trend in exploitation status of stock of sardine in the Adriatic Sea. The exploitation ratio (on the left) with a green area indicating the sustainable exploitation and a red area indicating the overexploitation status (F>F unique).

Adults status

Based on the last validated assessments results, the spawning biomass of Sardine in the Adriatic Sea shows an increasing trend over the mid-1770s, reaching their maximum observed value of about 764517 tons in 1982. Soon it followed by a significant decrease that continued until the year 2000.

In fact, the adult biomass started to reach low values since 1996 when the spawning biomass was roughly the threshold biomass reference point (250,636 tons), meaning that the stock was in a high risk to be overfished if no actions were made. Indeed, after this year the adult biomass dropped below the BPA (Fig. 40-top panel) and continued decreasing till reaching their minimum observed values near to limit biomass reference point (125,318 tons), indicating that the stock was in a high risk of collapse. Fortunately, some signs of improvement marked by a certain instability in the biomass level were observed from 2008 when an initial slight increase of SSB was observed followed by a decline in 2012 where the biomass returned to decrease reaching a level roughly 147561 tons. Subsequently, a second increase was observed that continued until 2015, year marked by a slight decline in adult biomass (Fig. 40-bottom panel).

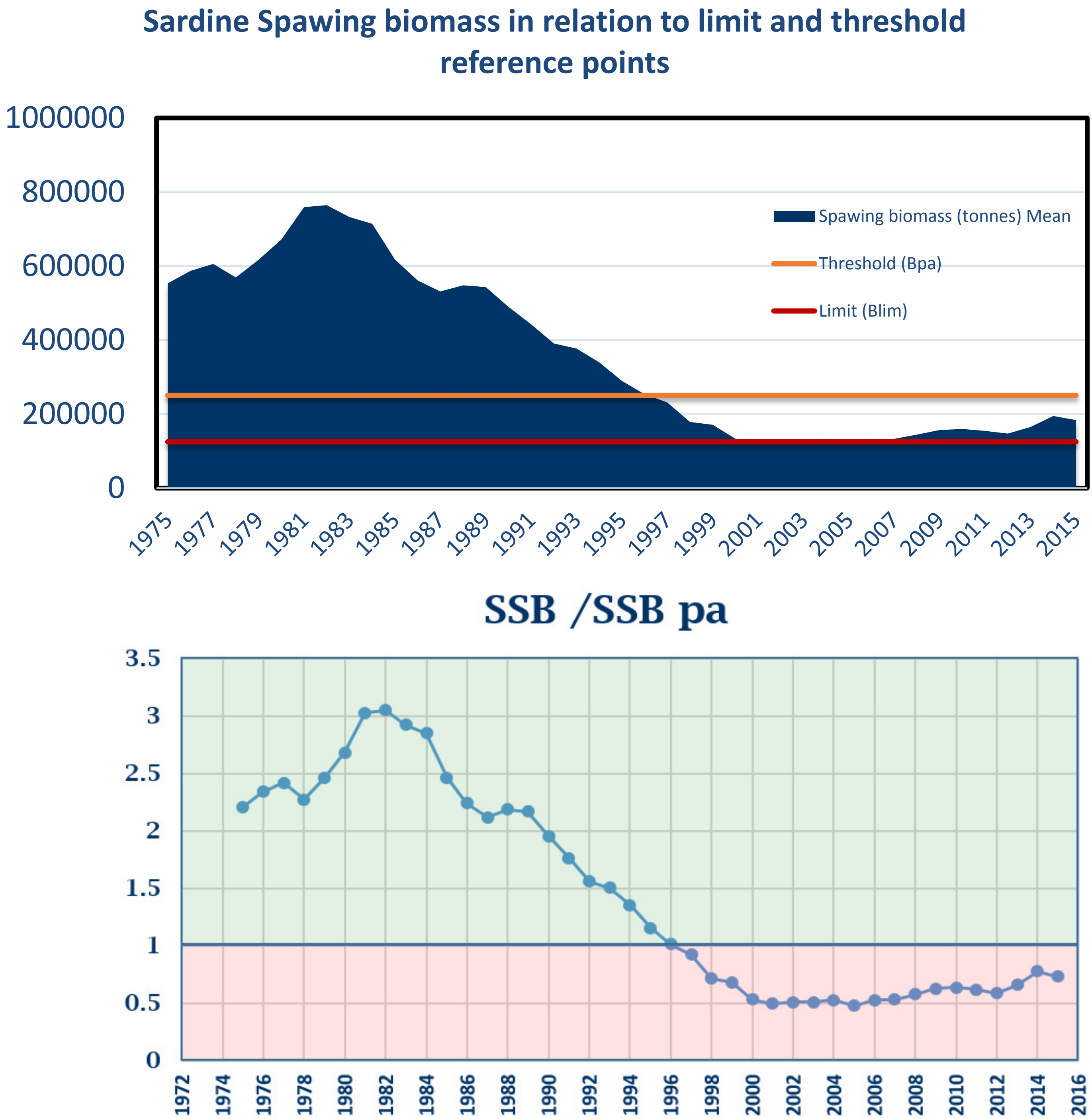


Figure 40: Trend in the Adriatic sardine spawning stock biomass in relation to reference points (top panel) and trend in spawning biomass ratio (bottom panel).

Juvenile's status

Overall, the recruitment trajectory follows the spawning biomass trend (Fig 41) marked by a downward overall trend. Until the 90s, the recruitment was well above the mean recruitment (26026833.29 thousand), since that time it drops below it.

At the beginning of the period the recruitment index remained steady at about 1.5 and it experienced an upward trend during the period 1975-1981, reaching the maximum of the entire time series at around 2 (53704105 thousand) in the end of this period. Afterwards, the recruitment gradually decreased to 1.5 in 1985, then it slightly raised in the next year. From the end of the 80s to the end of the 90s, the recruitment index declining significantly by around 1.5 to 0.38, respectively. In the following years, it stabilized in a low level that averaged roughly 10854534 thousand during the period between1998-2004, the recruitment since has increased continually showing hence some signs of improvement. Currently (2015), the recruitment index reaches a value at around 0.95 near to the mean recruitment of the entire time series (24716955 thousand).

The recruitment of a given year (x) is strongly (R squared equal 0.95) dependent on the biomass of adults in the previous year. Moreover, recruitment is generally lower when the SSB is below B_{LIM} (Fig. 42).

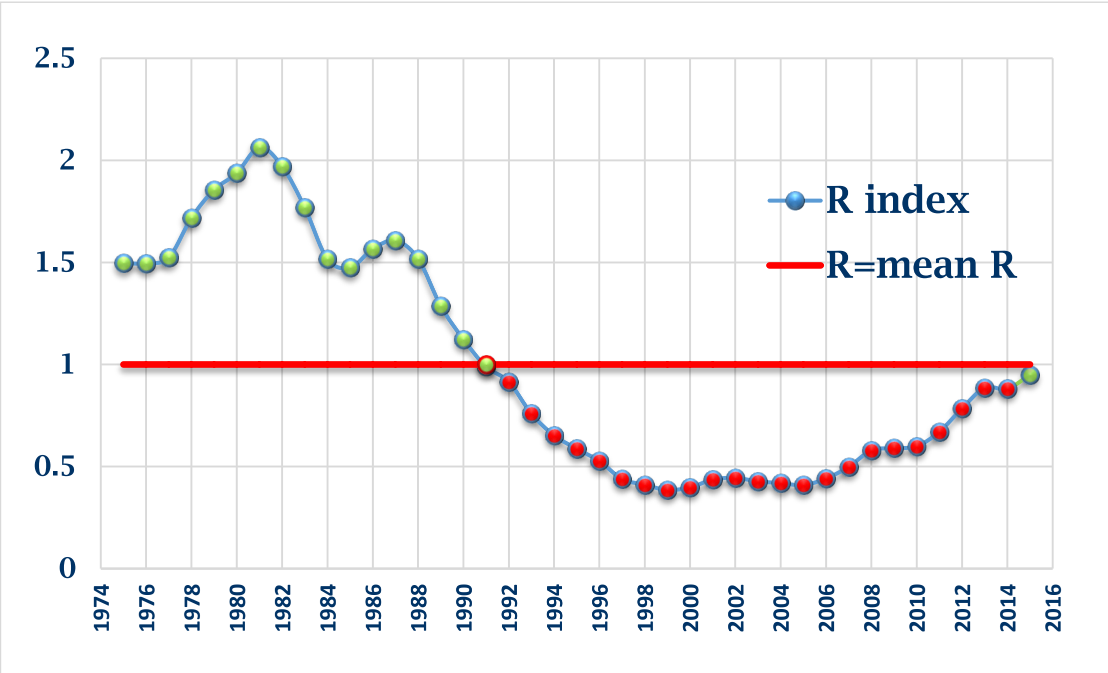


Figure 41: Adriatic sardine recruitment index (R/mean R) trend.

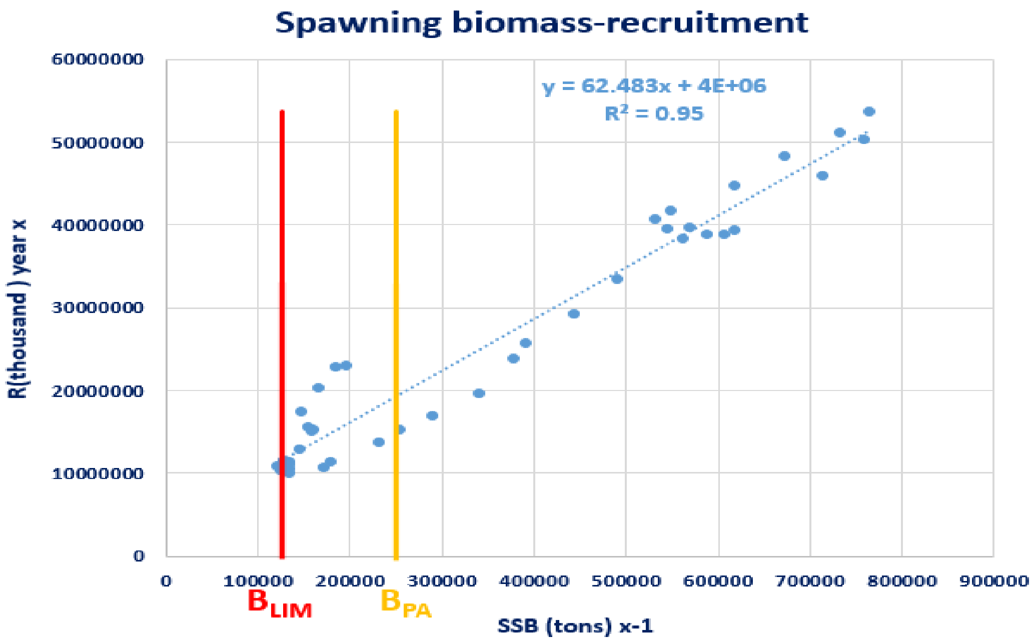


Figure 42: The correlation between Adriatic sardine Spawning biomass of year x and recruitment of the following year (x-1). In red color: B_{LIM}. In orange color: B_{PA}

Bi-dimensional status

The stock status trajectory computed from the last assessment outputs showed a significant gradually deteriorating status through the studied period, moving from the safe area to the high-risk area in the end of the period.

In fact, from the beginning of the time series up to 1996 the stock trajectory was located in the green quadrant, indicating that the stock biomass remained above the rates that would produce maximum sustained yields (F_{MSY}) and the stock of sardine in the Adriatic Sea was exploited rationally. Gradually, the spawning biomass ratio (B/B_{PA}) declined, though, remained below 1 in 1997, indicating that the stock was overfished. The stock status continued deteriorated and from 2011, the stock status trajectory positioned within the red quadrant, indicating that the stock is overfished and the overfishing is occurring (Fig.43).

There are some differences between the trajectory estimated from last assessment and that derived from the annual assessments over the considered period (2010-2015).

The second trajectory (blue rectangles) suggest that the stock was overexploited in 2010, afterward it was further deteriorated, being overexploited and in overexploitation in 2011 and 2012. Then, the stock status was improved in 2013, where the stock was only overexploited and the overexploitation not occurring. In the contrary, in 2014 the stock was in overfishing status and the spawning biomass above reference point and the end of the period the stock status become worst with both overfishing and being overfished in line with the trajectory derived from last assessment.

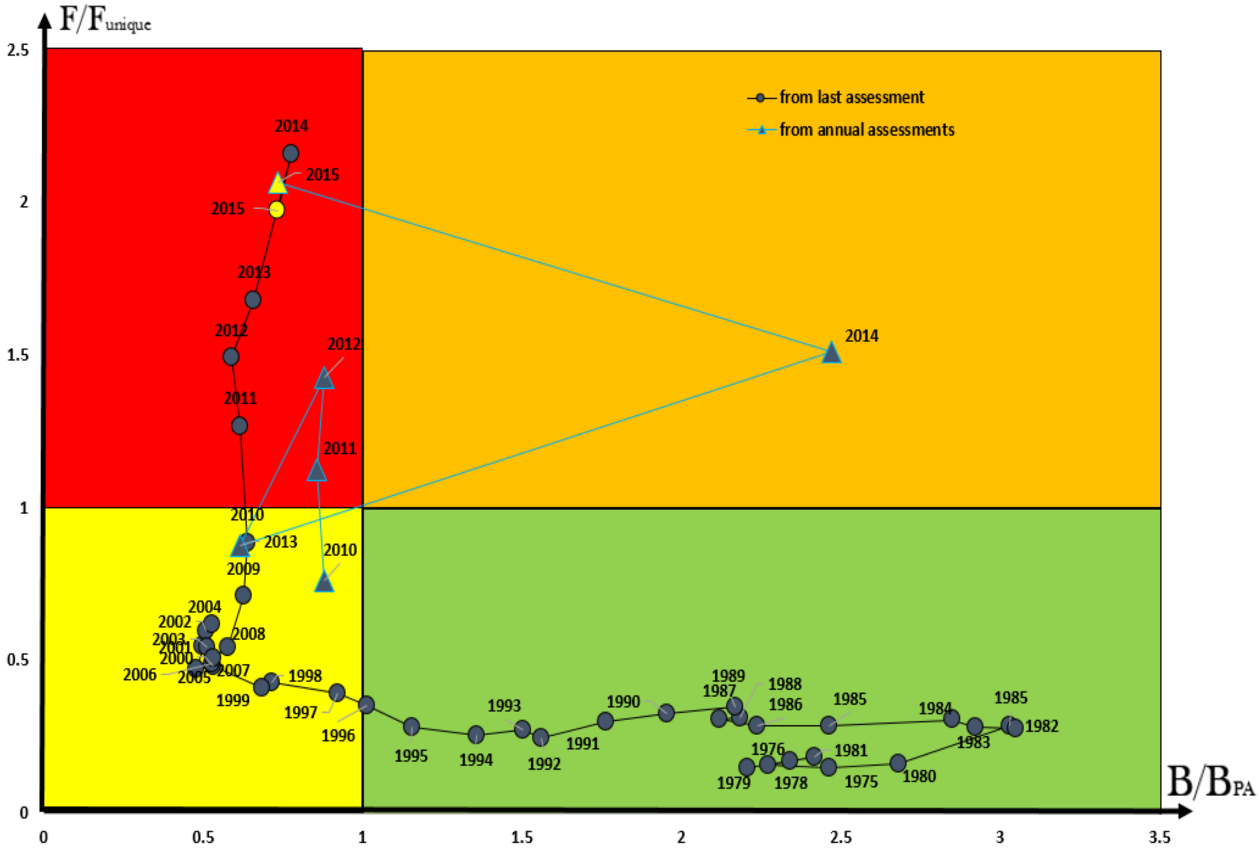


Figure 43: Stock status trajectory of Adriatic sardine status indicators (F/F_{MSY} and B/B_{PA}) derived from the last validated assessment (dotted line) and from the annual reported assessment results (blue triangles) on Kobe plot. The current status is marked with yellow color.

B. European anchovy

Comparative analysis

The comparison between time series of spawning biomass, total biomass, recruitment and fishing mortality from the last four assessments revealed a high agreement and consistency between 2015 and 2014 assessment estimates and between the two previous assessments carried out in 2012 and in 2013. While, a deviation and divergence occur between the outcomes of the last two assessments and of those resulting from the two previous assessments. The four assessments outputs shown a clear divergence in the terminal years (Fig. 44-2).

About the total biomass and spawning biomass, the last two assessments results have an exact match from the beginning of the time series until 2003 and 2005for TB and SSB, respectively. Then, the time series diverge from each other but still tracking the same trend. The time series from the previous assessments, i.e., 2012 and 2013, follow the same trend with an observed overlapping in the period 1978-1981, 1993-2004 and during 2006-2007(Fig. 44-1).

Concerning the recruitment successive estimates, an exact match was observed from the beginning of the time series until 2003 in the time series produced by the last two assessments estimates followed by a spacing continued until 2013 when the trend was reversed showing, hence, some inconsistencies in the terminal years estimates (Fig.44-3). More or less the same occur for the fishing mortality successive estimates (Fig. 44-4).

While, the time series of recruitment estimated by the 2012 and 2013 assessments overlap only in some periods but still so near each other and tracking the same overall trend until the last three years when the spacing became more significant. In contrast, the fishing mortality from last assessments estimates are closer to each other in terminal years (Fig.44-4).

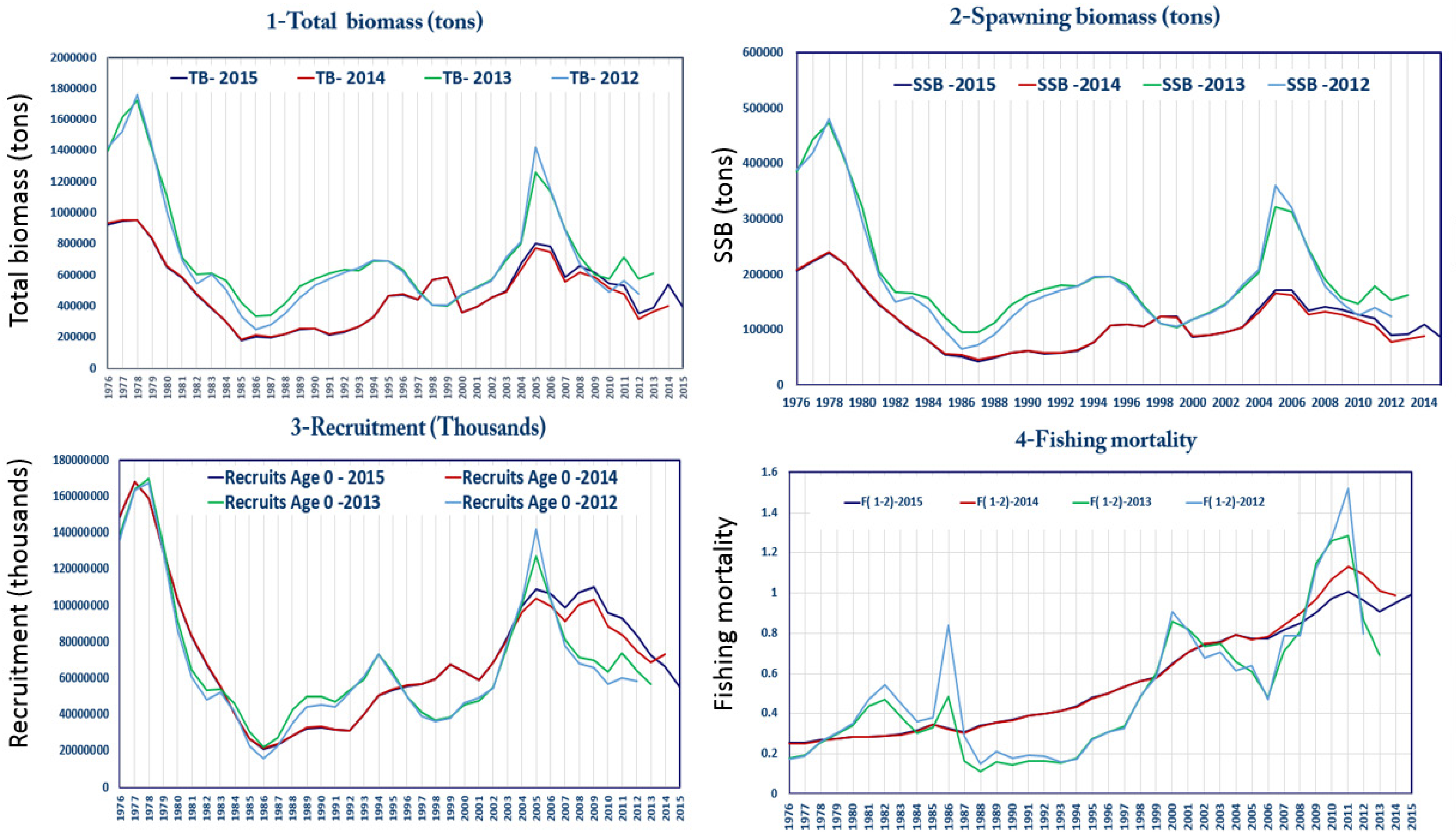


Figure 44: Comparative analysis between outcomes of last four successive assessments of Adriatic anchovy.

Except the indicator of fishing mortality, the time series from annual assessments (red line) are quite different than time series from one assessment (dark blue line), moreover, the time series from annual assessments present large fluctuation without any trend. In contrast, the fishing mortality time series follow the same trend with a match in the last two years (Fig.45).

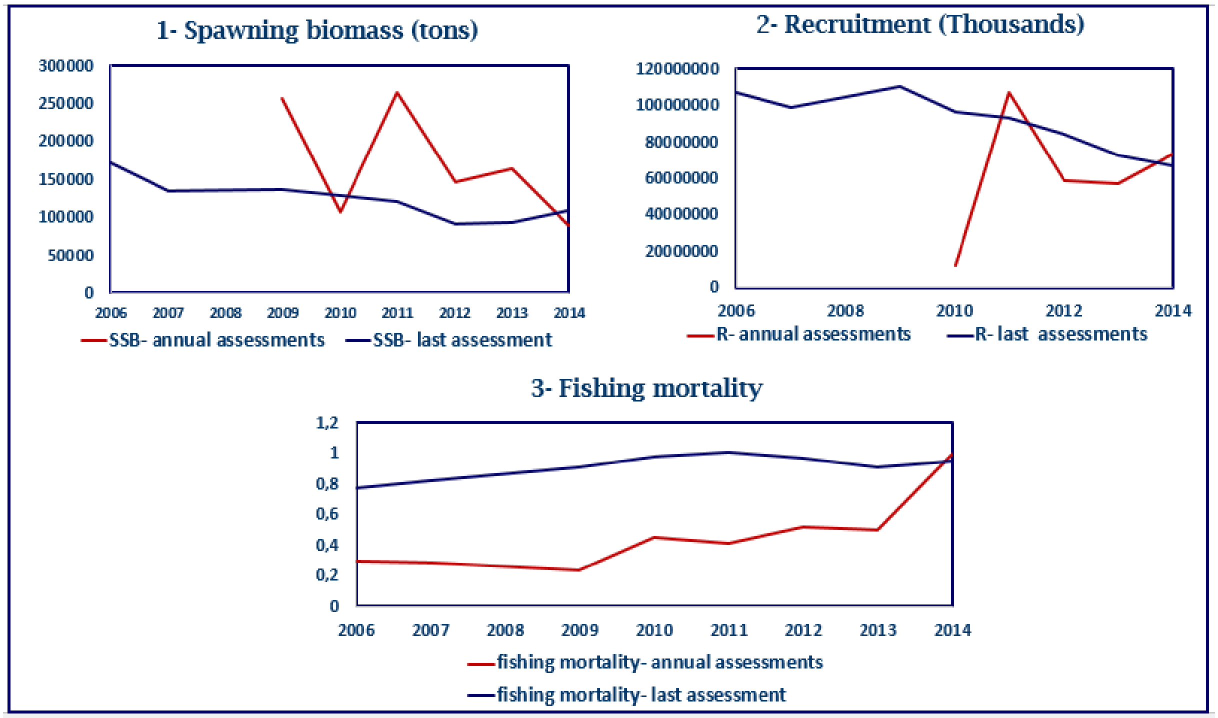


Figure 45: Comparative analysis between indicator time series from last validated assessment (dark blue line) and from annual reported indicators values (red line) of Adriatic anchovy status.

Single stock status

Exploitation status

The exploitation ratio shows a constant increase from the beginning of the time series up to 2011, when it reached the maximum observed value of about 1.8, followed by a slight decrease of about 0.2 to then increase to reach a value of about 1.8 in 2015. In fact, despite its apparent upward trend from 1975 to the end of the 90s the fishing mortality applied to the stocks of anchovy in the Adriatic Sea still below their associated reference point (F_{MSY} proxy), while, since that time the exploitation ratio starts to exceed one, indicating the stock experiencing the overfishing status (Fig. 46).

The fishing intensity increased constantly and, hence, the overfishing level too. Indeed, during the period 1998-2002 the exploitation ratio trajectory was located in the yellow area, meaning that a low overfishing was occurring. Then, due to the continuous increase in the fishing mortality applied to the stock, the exploitation ratio exceeded 1.33 in 2003 indicating that the stock of anchovy started suffering from an intermediate overfishing status, which become more serious in 2010 when the stock started experiencing a high overfishing status. Some improvement was observed in 2013 when the fishing mortality was decreased but soon started to increase, currently the examined stock is a high overfishing status (Fig. 46).

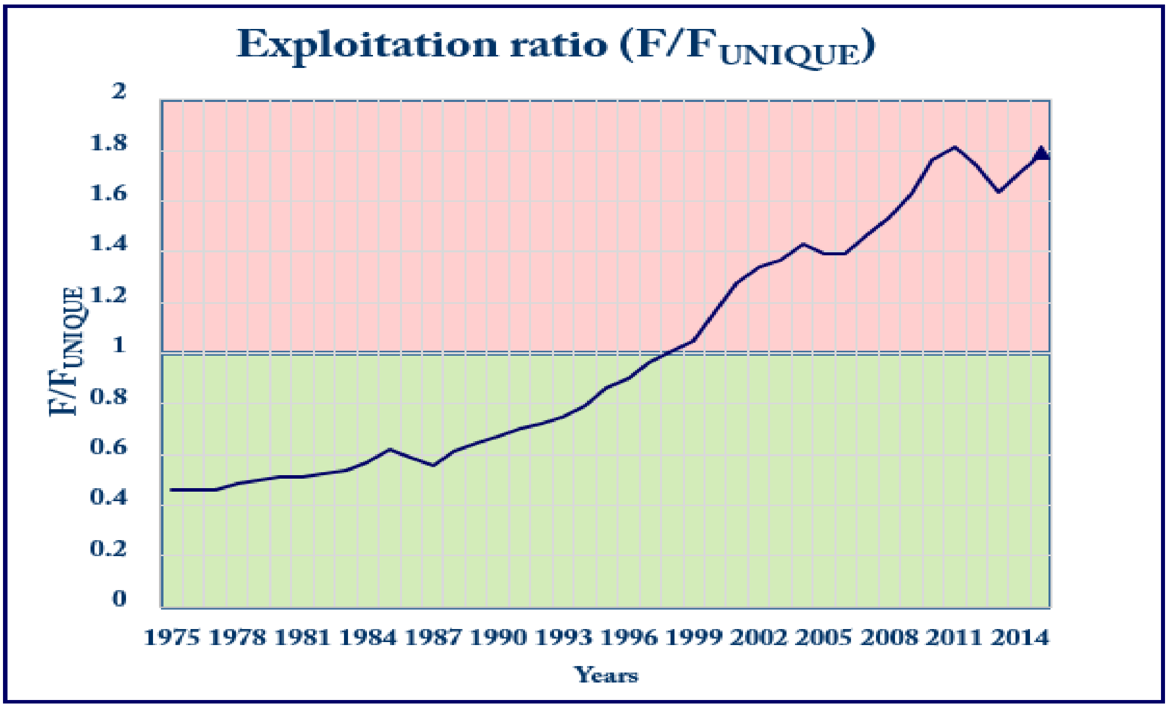


Figure 46: Assessment of the exploitation ratio (F/F_{UNIQUE}) of stock of Adriatic anchovy over the period 1975-2015 using trophic light approach.

Stock biomass status

From the beginning of the time series until 1982, the spawning biomass was located in the green area, meaning that the biomass was above the threshold reference point. Afterwards, the SSB dropped below B_{PA} indicating that the stock reproductive capacity was impaired. From 1995, the SSB showed a strong fluctuation but with a clear improvement, being principally located in the green area. Currently the stock is situated in the red area near to the intersection with the green zone indicating that a little increase in stock biomass in needed to ensure the reproductive stock capacity. The relative adult biomass was reached it maximum observed value in 1978, followed by a strong decrease continued till 1987 when the biomass was recovered and increased with apparent fluctuations till reaching a peak in 2005 to then return to decrease again (Fig. 47-a).

The recruitment index follows the same overall trend as the relative adult biomass, except in the last three years when the recruitment continues to decline, while, the relative SSB was showed some slight fluctuations (Fig.47–b). Moreover, a strong relationship exists between the adult biomass for the year x-1 and the number of recruits of the next year (x) with R squares equal to 0.87 and a slope positive and significant (p-value <0.05), meaning that up to 87% of the variance in the recruitment is due to and explained by the variance or the change in the adult biomass (Fig. 48-a). Likewise, the recruits of a given year (x-1) affects significantly (p-value <0.05) the reproductive biomass of the following year (x), which indicate that 73% of the variance in the spawning biomass of a given year is predictable from number of recruits of the previous year (Fig. 48-b).

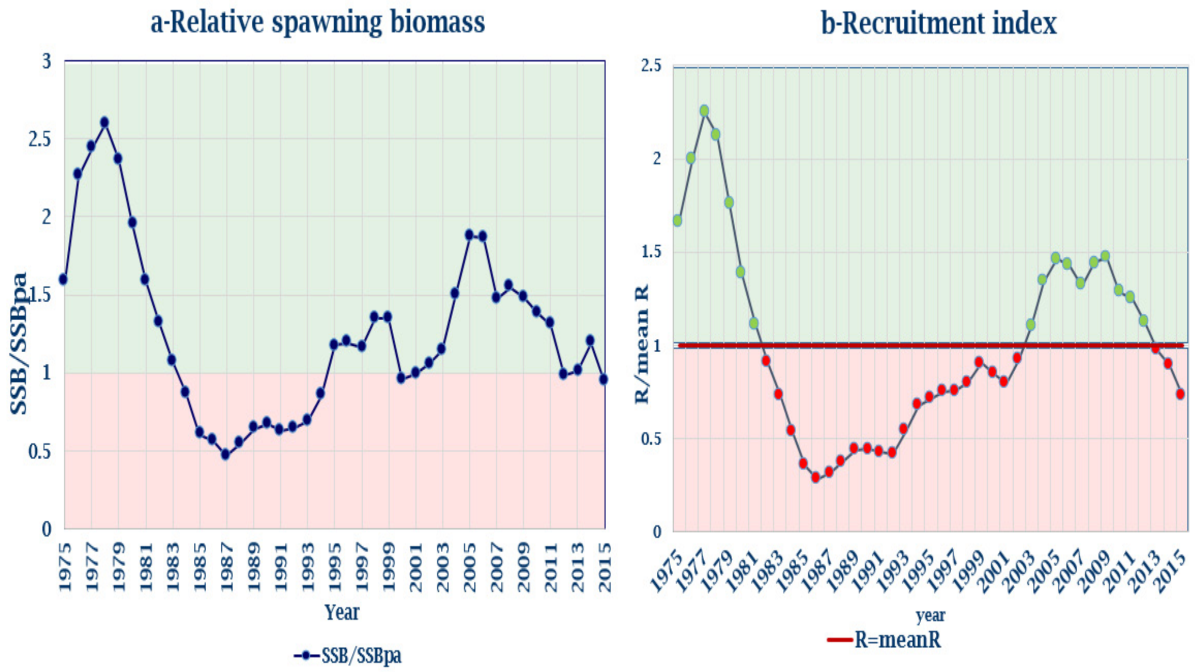


Figure 47: Assessment of biomass (a) and recruitment index (b) status of the Adriatic anchovy with a traffic-light approach.

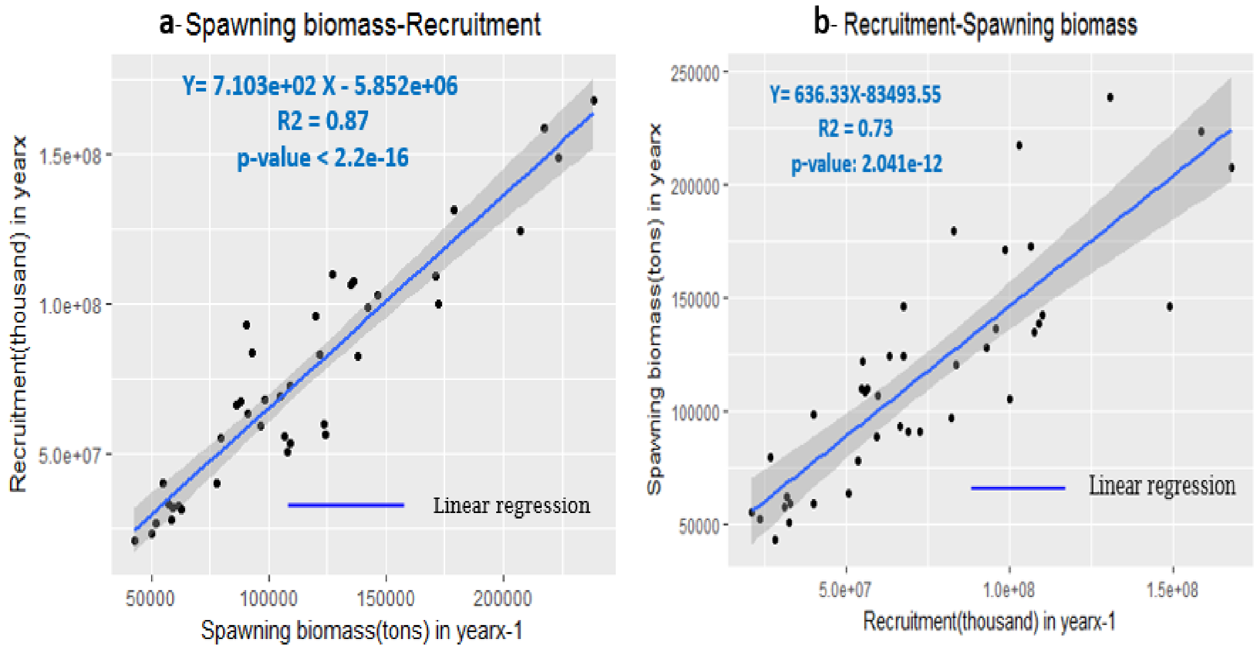


Figure 48: Relationship between adult biomass of year x-1 with recruitment of year x (black dots) (a) and Relationship between Recruits of year x-1 with reproductions of year x (black dots) (b) for the Adriatic anchovy. Blue line: linear regression between SSB and R surrounded by the 95% confidence interval (shaded region).

Bi-dimensional status

Despite the fact that the stock trajectory derived from the last assessment outcomes (blue line) and from the annual assessments (black line) differed in their absolute values, both of them suggest the same general picture, which indicate that the stock was in a good status in the early years then the situation was deteriorated gradually with the time till become worst in the terminal years when the stock was become in the same time overexploited and experiencing the overexploitation status (Fig.49).

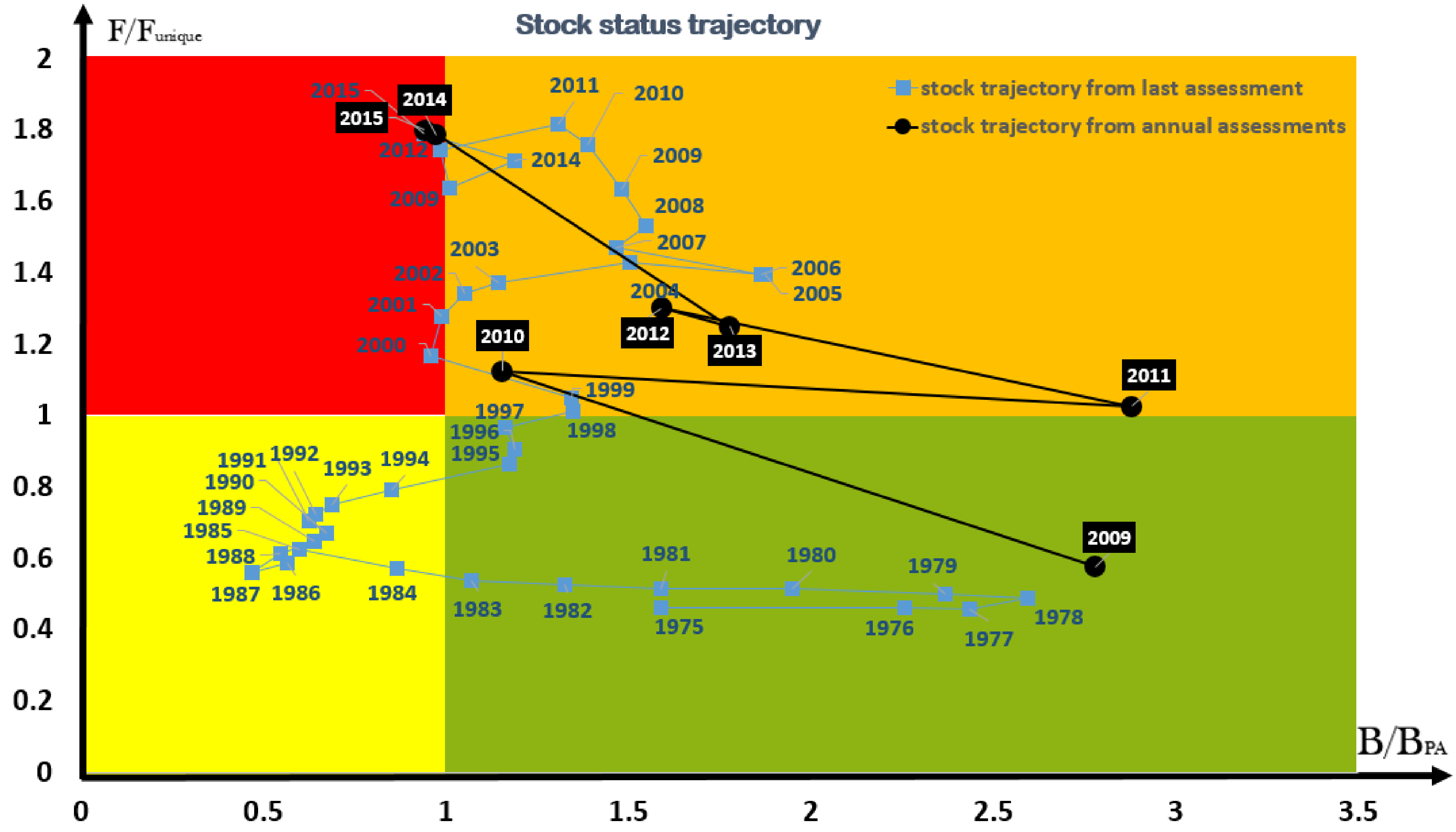


Figure 49: Stock status trajectory of F/F_{MSY} and B/B_{PA} derived from the last validated assessment (blue line) and from the annual reported assessments of the Adriatic anchovy (black line) represented on Kobe plot.

3.4.2. Strait of Sicily

3.4.2.1. Demersal stocks

A. Deep water rose shrimp

Comparative analysis

The successive stock assessment outcomes results are quite different from one assessment to another showing a clear retrospective pattern, especially in the estimated TB and SSB time series which not overlap, except the SSB estimated value for year 2013 provided by 2013 and 2015 assessments (Fig. 50).

The recruitment and the fishing mortality time series estimated by 2014 and 2015 assessments are quite similar. While, the time series provided by the assessment of 2013 are so far from the other times series and it appears that there is an error in the unit (billions instead million) reported to GFCM, in all cases the Recruitment estimated through this assessment still not overlap at all with the next assessments results (2014 and 2015).

In fact, all the 2013 assessment results follow more or less the same trend as the other assessment results but don't overlap with them and all the indicators are underestimated compared with the last validated assessment (2015).

About 2014 and 2015 XSA results, the recruitment as well as the fishing mortality time series estimates are overlap. The Total Biomass and SSB indicators estimated by 2014 assessment are underestimated compared with the last assessment results or, on the contrary, those indicators are overestimated by the last assessment.

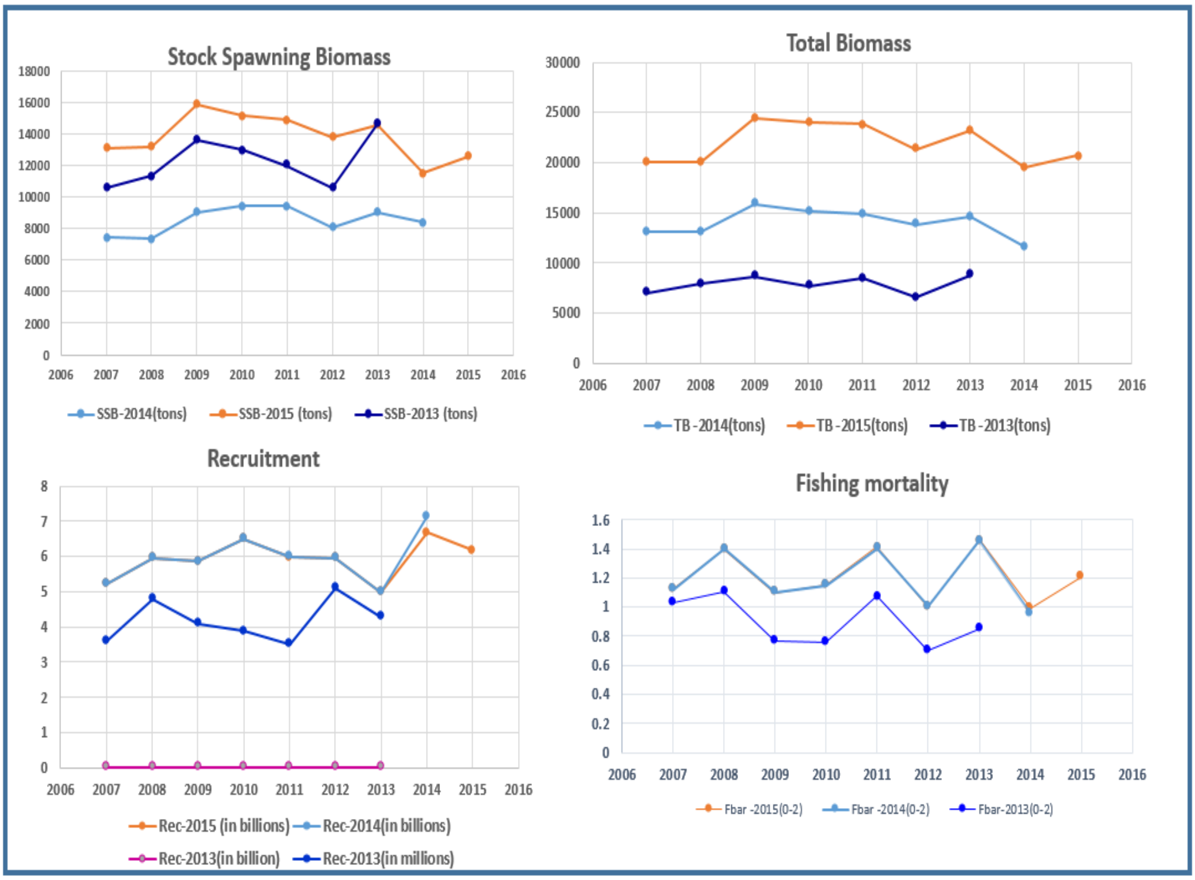


Figure 50: Comparative analysis between the last three assessment of *P. longirostris* results conducted by XSA model.

Exploitation status

The fishing mortality applied to the stock of *P. longirostris* is well above the established reference point in all the examined period (2007-2015). The exploitation ratio ($F/F_{0.1}$ (0.83)) trajectory (Fig. 51) indicates that the stock is suffering from an overfishing with a fluctuating level. In 2008, 2011 and in 2013 the stock was in an overfishing status high, in 2009 and in 2010 the overfishing was moderate, while in 2012 and 2014 the stock was subjected to an overfishing low. Currently, the stock is in overfishing status high (Fig. 51)

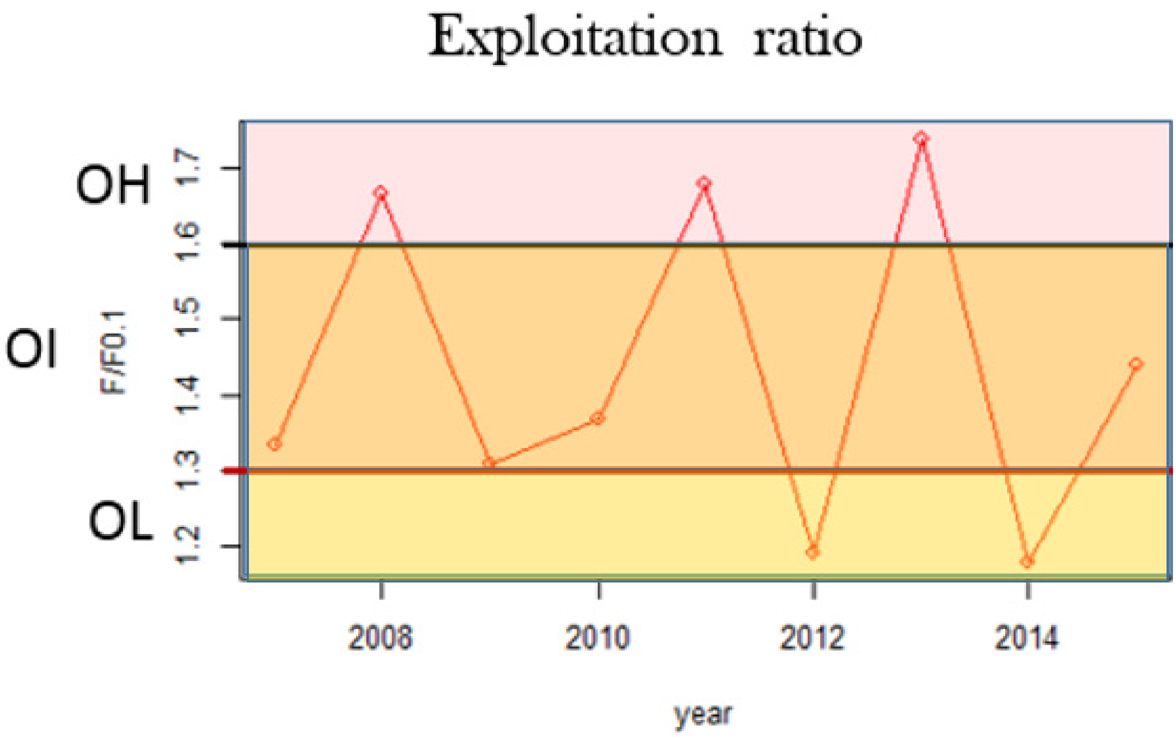


Figure 51: Assessment of the exploitation ratio (F/F_{MSY}) of stock of Deep-water rose shrimp in Strait of Sicily over the period 2006-2015. OH : high overfishing ($F/F_{MSY} \geq 1.66$) , OI : intermediate overfishing ($1.33 < F/F_{MSY} < 1.66$), OL : low overfishing ($F/F_{MSY} \leq 1.33$).

❖ ***Biomass status***

The total biomass and the spawning stock biomass follow the same overall trend. Indeed, at the beginning of the time series the TB as well as the SSB remains stable with values estimated at around 13000 and 20000, respectively. Then both TB and SSB indicators were increased significantly to reach their maximum observed values which were about 24400 and 15881 tons, respectively. Those pics are followed by an increase in the recruitment in 2010. The SSB was decreased continuously from 2009 to 2012, overall the recruitment was decreased till reaching the minimum observed value at about 4.97 billion in 2013. After that, the R increased significantly in 2014 when is reached their highest value of about 6.68 billion, this second pic is followed by a new observed SSB increase in 2013 (Fig 52- 1 and 2).

On the other hand, in 2013 the fishing mortality applied to the stock has reached his highest level of about 1.46 which corresponding to an exploitation ratio estimated at around 1.73, in other words the stock was subjected to high overfishing level. In the same year, the recruitment has reached his minimum observed value the recruitment index was around 0.84. Despite, the observed increase in the fishing mortality in 2011, the recruitment ratio was not very low and this can be justified by the good status of stock biomass which was above the associated reference point ($B>B_{PA}>1$) as shown the figure 52-1b.

In 2014, the TB and SSB showed a drastic chute when they reached their minimum level of about 19513.94 tons and 11489 tons, respectively. In this year, the biomass ratio was around 0.84 and the biomass status is defined as ‘’overexploited with low biomass level”. The high fishing mortality intensity plus the low recruitment observed in previous year (2013) are the main causes behind the deterioration of the stock status (overexploited with low biomass level and an overfishing status high is occurring) in 2014.

About the biomass status across years, as illustrate the figure 52-1b, the stock was overfished in 2007 and 2008, while the stock biomass was above the reference point during the period 2009-2011.since then, the stock was overfished and biomass ratio was reached the minimum level at around 0.84 in 2014. Currently the stock is still overexploited with an estimated biomass ratio around 0.89.

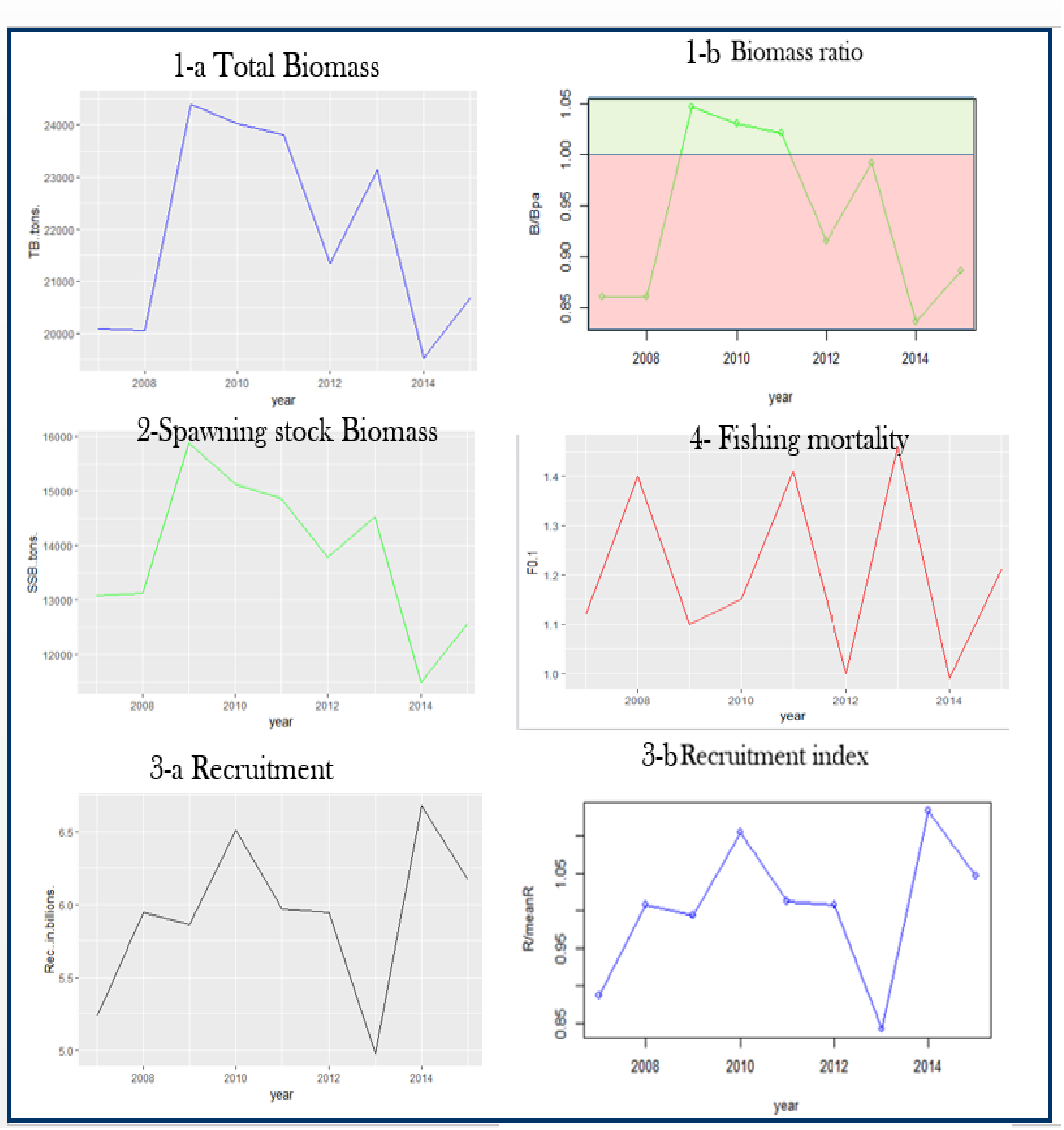


Figure 52: Indicators of stock biomass of Deep-water rose shrimp in strait of Sicily

Bi-dimensional stock status

The stock status trajectory from last assessment outcomes and from the annual assessments do not overlap but both confirm that over the recent years the stock of Deep-water rose in strait of Sicily is overfished and in overfishing status.

The stock status trajectory indicates that the fishing mortality applied to the stock of Deep-water-rose-shrimp is above the level that can ensure the maximum sustainable yield (F>Fmsy proxy) and that for during all the studied period (2007-2015). At the beginning of the time series, the stock was in the red quadrant indicating that the stock is overfished and the overfishing status is occurring, then the stock is increased and hence it was moved to the orange quadrant meaning the stock only in an overfishing status and stock size is above the reference point (Fig.53/ blue symbols).

In 2012, the status of DPS become worst given that has returned to the red quadrant. After that, despite the observed increase in the fishing mortality, the biomass ratio was improved compared to 2012 which lead the stock to be situated more nearly to the orange quadrant. The status of overfishing that the stock is suffering from was further complicated by the low recruitment quantity of new generation to the stock. Since then, the stock is overfished and the overfishing status is occurring. Currently, the magnitude of fishing mortality is estimated at about 1.44 -1.33 (is the range of F0.1 =0.84-0.93 are both considered) and that of the stock biomass is around 0.88 (Fig. 53)

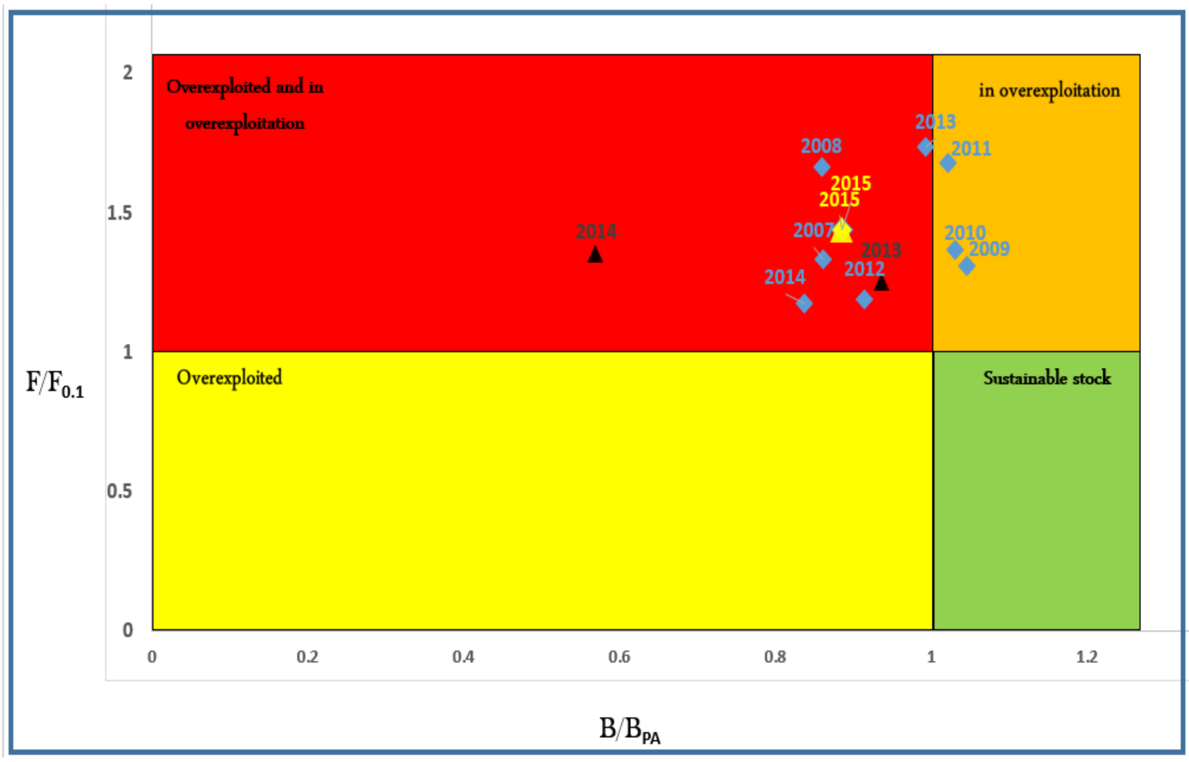


Figure 53: Deep water rose shrimp in strait of Sicily status trajectory. Black triangles: data from year-by-year approach. Blue symbols: data from last assessment output. Yellow color situates the current stock status.

B. European hake

Exploitation status

In fact, during all the examined period, the fishing mortality is well above the fishing mortality that can produce the maximum Sustainable yield, and therefore an overfishing status high is occurring. However, an apparent decrease in F was recorded in 2008 and in 2011 with a rate of decrees estimated at about -16% and -34%, respectively (Fig.54).

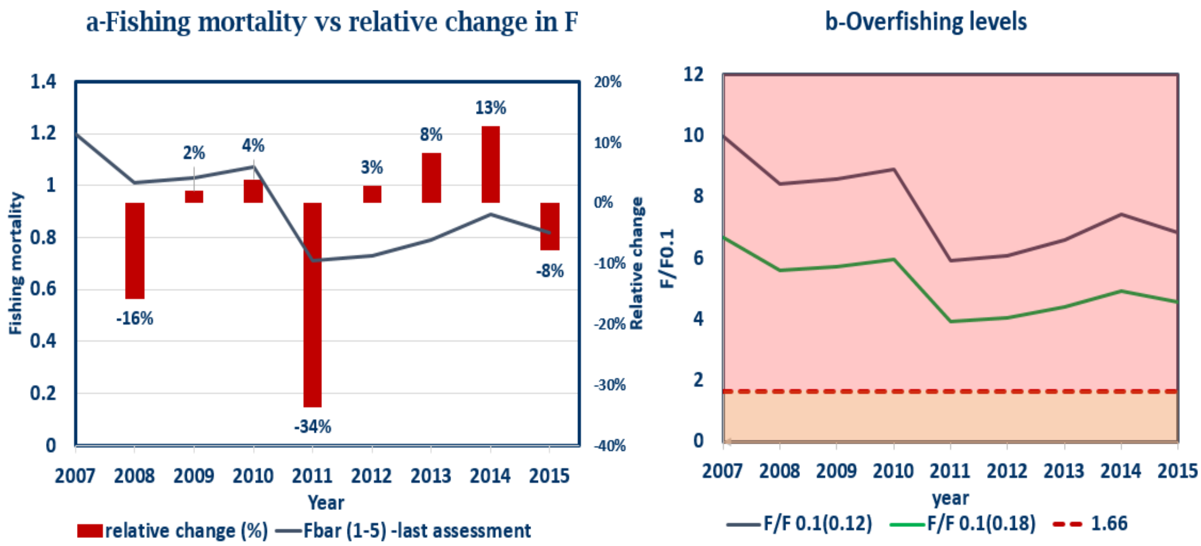


Figure 54: The fishing mortality of hake in strait of Sicily, their relative change over years (a) and the overfishing levels (b). Orange area: (1.33 <$F/F_{0.1}$ < 1.66), (intermediate overfishing), red area: $F/F_{0.1} \geq 1.66$ (high overfishing),

Biomass status

During the period 2007-2010, the spawning stock biomass was more or less stable in a low value. Then a significant decrease was observed in 2011, when the stock adult reached their minimum observed value estimated at about 5477 tons. Since that time, the SSB follows an increasing trend, except in 2015 when the stock was decreased slightly. In fact, the biomass ratio indicates that the SSB ratio was below one during all the period 2007-2012. In other words, the stock was overfished and therefore the stock reproductive capacity was relatively impaired. Although, from 2011 some signs of improvement were observed when the adult biomass started to increase continuously. Fortunately, the stock seems to be redressed in 2013 when the empirical threshold reference point (66th of percentile of biomass) was exceeded (Fig. 56-a).

The recruitment index presents an instability with apparent fluctuations. The maximum value was observed in 2011 when the recruitment reached a value of about 268 million (Fig.55). While, the proportion of survival follows a significant increasing trend with R squared estimated at about 0.68 with a positive scope and p-value below 0.05.

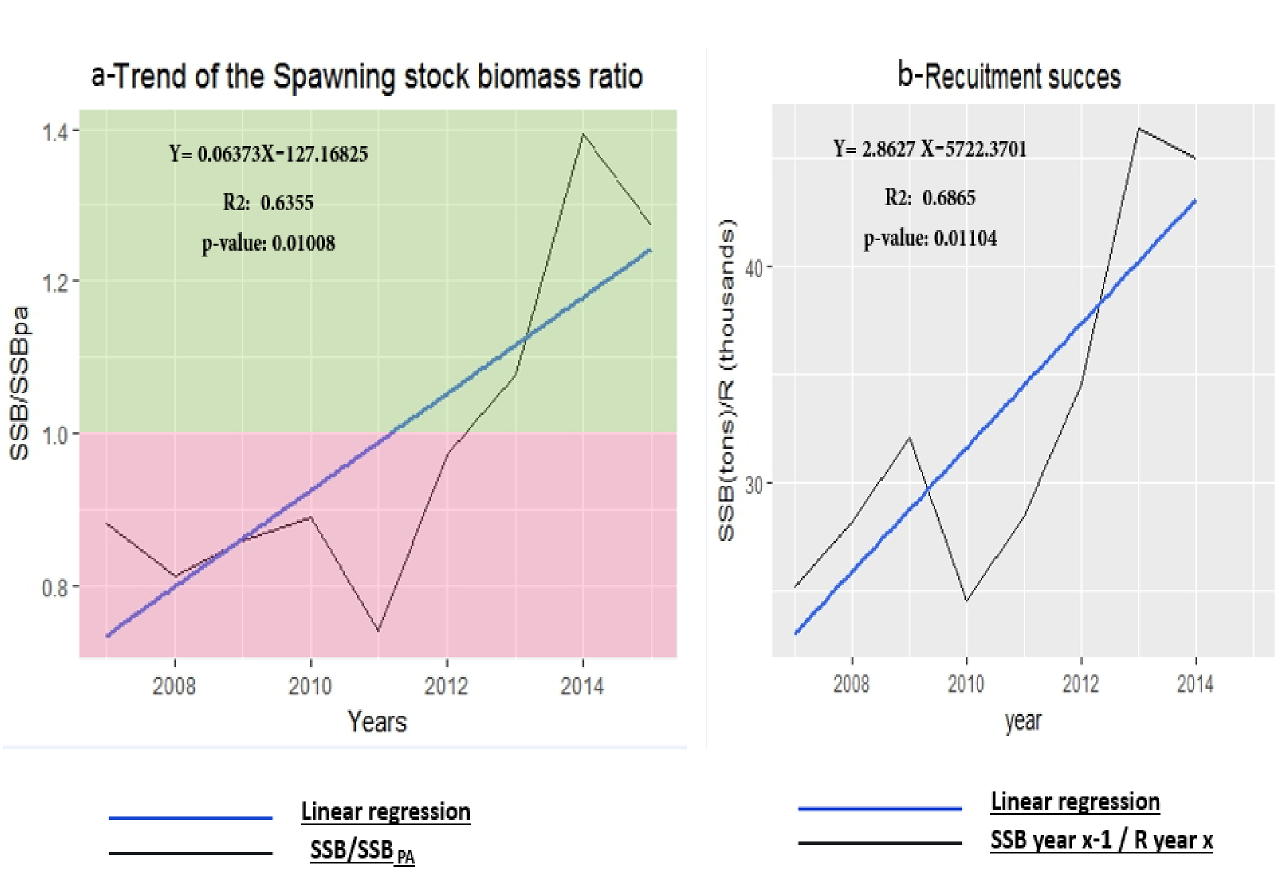


Figure 56: Trend on ratio of spawning biomass (SSB/SSB $_{PA}$) of the stock of hake in strait of Sicily assessed applying *traffic-light* approach (a) and proportion of recruitment success computed as the ratio between the SSB(tons) of year x-1 and the absolutes

Figure 55: Recruitment index (R/mean R) of stock of hake in strait of Sicily assessed applying traffic-light approach

Recruitment (thousand) of year x.

Bi-dimensional status

From the 2007 to 2012, the stock was located within the red quadrant indicating the stock is overfished and an overfishing is occurring. While, from 2013 the stock is moved to the orange quadrant indicating the stock biomass is above the reference point while the fishing mortality is still unsustainably and the stock is in overfishing status qualified as high (F/F0.1>1.66) (Fig.57)

The Kobe plot confirm the stock biomass is in good status while the harvesting pressure, fishing mortality, is so high and overfishing status high is occurring. The high fishing mortality applied to the stock specially targeting the small individuals make the stock is a high risk.

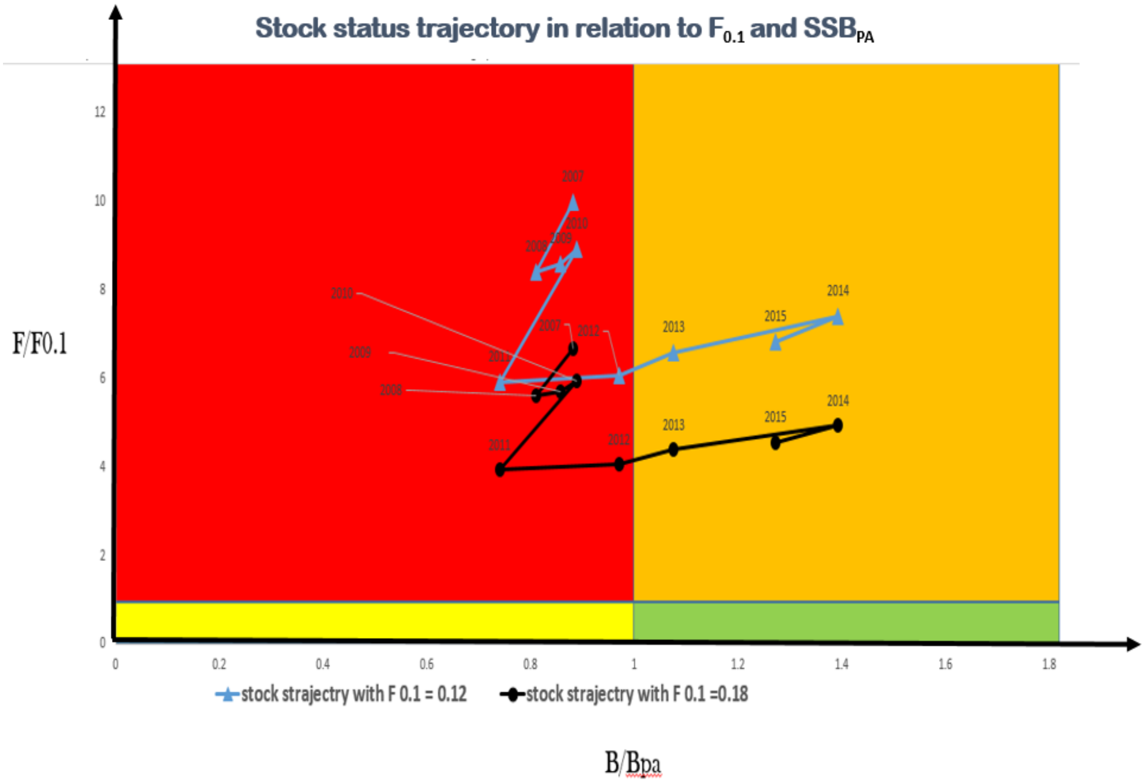


Figure 57: Trajectory of the state of stock of hake in Strait of Sicily represented on Kobe plot using $F_{0.1}$=0.12 (blue line) and F0.1= 0.18 (black line).

4. Discussion

4.1. Limitation and difficulties

With the aim to provide a spatio-temporal analysis of Mediterranean stock status based not only on the most reliable recent data but also on indicators and reference points as most certain as possible, this work was based only on the endorsed assessments by either SAC of GFCM or STECF of European commission. Despite that many obstacles were fixed, however, some limitations persist which can be a scope of improvement in the future. Amongst them, (i) the spatio-temporal coverage of stocks considered in the analysis, (ii) the shortness of indicator time series used, (iii) the absence of analytical biomass reference points and (iv) the issue of standardized data at regional level.

Even though the efforts made to collect all the available data on stock assessments to cover as possible the whole studied area, the Eastern and Central Mediterranean are still not well represented in this analysis due to the fact that the vast majority of assessed stocks are located in the western part of the Mediterranean, whereas, the eastern stocks are rarely assessed presenting a low percentage of assessed landing.

This point raises another major issue that face providing deeper analysis, is about the issue of the shortness and the incomplete indicator time series. This is due to several raison, among them the fact that some assessments were conducted with the frame of regional projects without continuity over time and because the assessment of large number of Mediterranean stocks are relatively recent due to the unavailability of a long time series of data, lack of the data collection system at national level for many GFCM member states and/or the reject of the considered data in performing assessments presented to SAC as a consequence of their unreliability or inconsistency.

In fact, GFCM through SAC and its technical bodies, such as the Working Group on Stock Assessments (WGSAD and WGSASP) was already made a considerable effort to develop and improve the estimation quality of the adopted indicators and associated reference points. However, the computation of some of these indicators and associated reference points present some gaps and limitations. Among them the issue of the data collection, in effect big differences exist in the framework of data collection between the Mediterranean European Union countries and the others. The first ones collected both dependent and independent data in a harmonized way at the Mediterranean level, their dependent-data are collected within the framework of an international surveys (MEDITS and MEDIAS) designed by the European commission, so that data are unbiased and reliable. In addition, their dependent-data are collected within the framework of the EU Data Collection Framework (DCF). All this allow them possessing a reliable, harmonized, and regular data and hence performing a stock assessment regularly and correctly, which justify the fact that the most validated assessments come from this area.

In contrast, the countries not belonging the European Union collect the dependent data through national surveys that are designed at national level and, in the most cases, they are not subject to some international standards and they are not coherent at regional level as well. This issue was further complicated with the absence of a regional data collection framework for many years.

As mentioned several times during the working group meetings, the lack of a reliable data as well as the shortness of the time series faces the use of a more advanced assessment model such as XSA and Stock Synthesis3 (SS3), even it made performing assessments in numerous GSAs impossible.

This issue sends us to another problem that suffer the stock assessment within the GFCM area, it concerns the wide range of stock assessment model used to assess the Mediterranean stocks, not only across GSAs but also across years within the same GSA. Given that each model is based on some assumptions, requires specific data, can estimates only some specific indicators and have some level of uncertainty to estimate results the harmonization and the coherence of the assessment results at regional level, mainly the indicator of stock status, must be putted into question.

Furthermore, the biological reference points (B_{LIM}, $B_{THRESHOLD}$ and B_{MSY}) are not yet defined for the majority of assessed stocks, also find by Vasilakopoulos *et al.,* (2014). To assess their stocks, the GFCM national experts that form the SAC working group on stock assessment are adopted an empirical set of reference points namely the 33rd and 66th percentiles of biomass, which are used as a B_{LIM} and B_{PA} respectively. Those empirical reference points are estimated from the biomass time series and therefore present a dependence to the shortness of the time series. In fact, whenever shorter is the time series whenever the estimate was less reliable. Therefore, it must be bear in mind that quantile-based approach only indicates the relative change in the time series mean, and hence, the biomass ratio indicator informs only about the status of stock biomass relatively to the mean from the beginning of the used time series and do not take into account what occurred in the previous period (Pobst *et al.,* 2013). So, the use of the percentiles as a reference points must be used only if it is justifiable. If they are used, it has to be treated with caution and at least the analysis must be simultaneously accomplished with other information and indicators such as the catches, the biomass index, stock composition and length and age frequencies in the catches as well as the fishing mortality applied to the stock

4.2. Discussion

4.2.1. Trend on status of Mediterranean stocks

The assessment of the exploitation status of Mediterranean main fisheries for the period 1975-2015 suggests an ongoing overexploitation from the beginning of the 80s. Our results indicate a strong increase in the fishing mortality, which continued until 1987. Afterwards, the fishing mortality was stabilized around this high level to decrease then significantly in the period 1987-1990. The observed increase in the exploitation ratio as well as its followed strong decrease are likely due to the observed increase and decrease shown, successively, in the exploitation intensity applied to the hake stocks. In parallel, data on total Mediterranean landing show a rapid and strong increasing trend until 1990 when an apparent drop was recorded (Tsikliras *et al*., 2013; FAO, 2016-a). This decline in the catches is explained by the observed decrease in the total exploitation rate revealed by our results, especially that applied to hake stocks. Afterwards, data on catches indicates an apparent recovery in 1995 when a peak of about 1 128 000 tons was reached (Sauzade and Rousset, 2013), which is in accordance with our results that indicate a considerable increase in the regional exploitation ratio from 1990 onwards.

Contrary to expectations, it was revealed through our findings that despite the substantial increasing trend in the fishing mortality which occurred from 90s onwards, also revealed by Vasilakopoulos *et al.,* (2014), no positive response was shown in the catches. On the contrary, since that time, the catches have been following a continuous and irregular decline except in 2006 when a peak was recorded, especially due to an exceptional catch of small pelagic (Sauzade and Rousset, 2013). Similarly, the breakdown of the catches by sub-regions conducted by this present study detects a peak in the Western, the Central and the Eastern Mediterranean small pelagic production (GFCM capture production).

This finding suggests that no farther room of expansion is expected from the Mediterranean commercial stocks production, therefore unless a relevant increase of productivity happens, maximum sustainable catches are probably around or below the catches reached in the middle 90s.

Concerning the exploitation status by species group, this study findings confirm the previous study results (Vasilakopoulos *et al*., (2014); FAO, 2016-a). In effect, the results show that, overall, demersal bony fish are in the worst state with the highest exploitation intensity followed by the demersal crustaceans and small pelagic. In effect, the small pelagic stocks were exploited rationally ($F/F_{MSY} < 1$) until 2001, when the aggregated fishing mortality exceeded-for the first time- the target level ($F=F_{MSY}$). Since then, a continuous increase became evident. This increase is especially due to the continuous increasing trend in the exploitation intensity of sardine stocks that became more rapid from 2004 onwards. This increasing trend was also shown by Cardinale and Scarcella (2017).

On the other hand, a slight decrease is noted in the aggregated ratio F/F_{MSY} of crustacean stocks explained by the observed decrease in the exploitation ratio of Deep-water rose shrimp (DPS), Norway lobster (NEP) and Red shrimp (ARA) stocks. Similar to our results, a decreasing trend in the ratio F/F_{MSY} of Deep-water rose shrimp as well as of Red mullet was reported in Cardinale and Scarcella (2017). From all the examined species, the hake stocks were the ones exploited at the most transgressing rates F_{MSY} (confirmed in Vasilakopoulos *et al*., 2014) ($F/F_{MSY} > 3$ after 1990), while the anchovy stocks were the closest ones to the associated reference point (exploitation ratio around 1.4 from 2008 onwards).

The most recent study (Cardinale and Scarcella, 2017) about the exploitation status of Mediterranean stocks proved that the reduction in fishing effort, especially the nominal effort, do not correspond to a reduction in the fishing mortality (F) in all Mediterranean stocks. As stressed in Rebeiro *et al*., (2015) , the nominal effort is far from being an actual measure of the real effort of the fleet. It is specially the case of the trawlers and the purse seiners (Cardinale and Scarcella, 2017), the main contributors fleet segments to Mediterranean total catches (FAO, 2016-a). In fact, this finding explains why in spite of all the efforts made to reduce the exploitation intensity through controlling the fishing effort in this area no evident positive feedback has been achieved for many fisheries.

Moreover, another recent study (Vasilakopoulos *et al.,* 2014) explored simultaneously the trend of the aggregated rate of F/F_{MSY} and the gear selectivity (expressed as the aggregate relA50). Its results revealed that the gear selectivity decreased continuously in 1990-2006 and it was stabilized in negative values from 2006 onwards. Moreover, this study illustrates that the most overexploited stocks are harvested mainly before the size of first maturity of their individuals as is the case of hake stocks where the overexploitation of juveniles was particularly evident and with fish being selected on average 0.6-1.9 years before they matured. On the other hand, the small pelagic are selected on average more than 0.4 years after they matured, which explain why this species is in a better state compared with the demersal bony fish stocks, notably the hake stocks.

On the other hand, the relative SSB decreased significantly until the year 2000, in accordance with the finding of Vasilakopoulos *et al*., (2014). However, the relative SSB dropped with a considerable decreasing rate estimated at about 40%, 22%, and 0.30% during the periods between 1980 and 1990, 1980-1990, 1990-2000 and 2000-2010. Moreover, a slight improvement, from 2008 onwards, was observed in the spawning biomass of the demersal bony fish, especially in the spawning biomass of the Red mullet stocks that already showed a significant decreasing trend in the relative exploitation ratio (F/F_{MSY}). This finding supports the fact that the reduction in the fishing mortality directly and positively affects the stock biomass status. The spawning biomass of small pelagic stocks was decreased strongly from the beginning of the time series until 2005. Since then, however, no particular trend has been detected.

Performing a meta-analysis of Mediterranean stock status reveals also that the meta-analysis is a very useful approach in summarizing data and exploring the state at regional scale, however, many important details are hided. Therefore, it must be accompanied with the data break down at sub-scale also concluded by Sparholt *et al.,* (2007).

4.2.2. Current Status of Mediterranean stocks

The examination of the current status of 84 Mediterranean stocks based on the validated assessments either from SAC of GFCM or from STECF of EC indicates an alarming status for the vast majority of the Mediterranean assessed stocks either in terms of the biomass status, the exploitation intensity or both criteria.

The assessment of the current status using the relative exploitation (F/F_{MSY}) indicator that measures the distance between the fishing mortality applied to a given stock and the exploitation level that can ensure the stock sustainability (Froese *et al*., 2013) announces a worrying status. In effect, it was demonstrated that 73 out of the 84 included stocks are subject to overfishing. In other words, near to 87 % of Mediterranean commercial stocks are in a risk to be lost if no action is taken immediately. This finding is in a perfect accordance with the last review of the status of the Mediterranean and Black Sea stocks carried out by GFCM and published in the first edition of the SoMFi (FAO, 2016-a). In light of this review, it was concluded that around of 85 % of the examined stocks (for which F_{MSY} or its proxy is available) are fished unsustainably.

This slight difference is mainly due to two principal reasons. The first is related to the time dimension, given that in SoMFi they only examined the latest validated assessments until 2014 (reference year) included, whereas in our study the period was extended to englobe the most recent validated assessments (2015). The second is related to the spatial coverage of the considered stocks, given that the present study encompasses also the assessments presented to STECF that have never been submitted to SAC of GFCM.

In terms of the relative biomass indicator, the analysis of 57 different stocks along the Mediterranean Sea shows that around 68% of the reviewed stocks have a biomass below the biomass threshold (B_{PA} or its proxy), while only about 32% have a biomass above the associated threshold reference point. In fact, recently Froese *et al*., (2016) were analyzing the status of European stocks and they found that in the Mediterranean and the Black Sea region the average biomass is less than half (44%) of the sustainable level. Overall, this finding is in line with the present study results with some slight difference that can be explained by the fact that our analysis concerns all the Mediterranean stocks, considering the European and no European fisheries, whereas in Froese *et al*., (2016) only the European stocks were included. Furthermore, in the present study, the proportion of stocks with biomass above or below the reference point was used to inform about the regional status, while the other study adopted the average biomass as a regional indicator of stock status.

Moreover, the aggregated ratios F/F_{MSY}, using the arithmetic mean across stocks, illustrate that on average Mediterranean stocks are exploited three times greater than the target level and the biomass is lower than the threshold reference point, which confirm a regional status of overexploitation. In effect, in contrast to the relative Mediterranean biomass, the indicators of dispersion show a high dispersion in the ratios of exploitation intensity (F/F_{MSY}) across Mediterranean stocks, which spread from a ratio of about 0.010 to 12.80 observed in the stocks of Sardine and European hake in Gulf of Lions, respectively.

The assessment of stock status based on a simultaneous analysis of the status of stock size and fishing mortality is more informative and provides a more complete view on the real situation of the stock than conducting a uni-dimensional stock status that is evaluated as not enough to conclude on stock status. Indeed, this study's results clearly show that the status is becoming more pessimistic when both indicators of stock status (relative biomass and fishing mortality) are simultaneously taken into account. That given; only a minority filled the criteria to be classified as safe stocks. On the contrary, 90.9% out of examined stocks were estimated to be outside safe biological limits, either they are assessed as overfished only, subjected to the overfishing status only or, at the same time, they are overfished and the overfishing is occurring. Similarly, a consultation on the fishing opportunities for 2016 under the Common Fisheries Policy that was submitted to the European commission revealed that only 9 % of assessed fish stocks are fished at levels below MSY (COM, 2016).

Concerning the stock status by sub-region, it was shown through the present study that the Western Mediterranean and the Adriatic Sea are the most overfished Mediterranean sub-regions with a percentage of about 94% and 90% of stocks outside safe biological limits, respectively. While, the Eastern Mediterranean has reached a percentage of deteriorated stocks of about 75 %, which suggest that it is the least overfished area. However, only 7 Eastern Mediterranean stocks are assessed from 2009 onwards, from which only 4 stocks were included in the bi-dimensional analysis due to the unavailability of the biomass reference point, which is a very low number compared to the Mediterranean biodiversity. In addition, the catch analysis confirms that those species represent only a 7% of the Eastern Mediterranean total landing. So, we cannot conclude about the status of this sub-region on the whole. In this respect, a recent study on the status of Mediterranean stocks based on the catch-based method concludes that the Eastern Mediterranean is the most overfished area (Tsikliras *et al.,* 2015).

Between species groups, small pelagic are showing the best stock status in terms of both stock size and fishing mortality (considered separately) compared to the demersal crustacean and the demersal stocks. However, the small pelagic as well as the crustacean stock biomass are more concentrated around their average, while the demersal bony fish biomass ratios have the highest dispersion as indicate many indicators such as the variance, standard deviation, the range and the interquartile range. Fish stocks relative biomass spreads from a low value of about 0.17 to a high value of 2.7. Moreover, its interquartile range is equal to 0.653 against 0.395 and 0.44 for small pelagic and crustacean stocks, respectively.

On the other hand, on average, the demersal fish suffers from the highest overexploitation level, in line with SoMFi (2016-a) and Vasilakopoulos *et al.,* (2014). However, this group has also shown a high dispersion in the exploitation ratios across the Mediterranean stocks.

Although small pelagic are in a better state compared with the other studied species groups, the simultaneous analysis of stock status indicators that are presented on Kobe plot suggests that, on average, all Mediterranean species groups are overexploited and in overexploitation.

When looking at the species level, we clearly notice through the results that a considerable number of stocks are in a severe overexploitation status, especially the stock of European hake in Gulf of Lions that is excessively exploited. It is currently fished around 13 times higher than the rational exploitation level, confirmed in FAO (2016-a). High exploitation rates also apply to the Black-bellied angler *(L. budegassa)* in Balearic Islands and the Blue Whiting *(M. poutassou*) in Northern Spain, which are exploited, respectively, 10 and 9 times more than the level that can produce the maximum sustainable yield, in line with OCEANA (2016-a). The aggregated exploitation ratio by species across the Mediterranean have shown a status of overexploitation for all assessed stocks except *S. smaris* and at the forefront appears the *M. merluccius* with the highest exploitation ratio, which is also found by FAO (2016-a).

Among the minority of stocks that were classified as rationally exploited, we also found the sardine in the Gulf of Lion given that its rate of exploitation (E current) is well below the precautionary threshold of 0.4 recommended for small pelagic. However, this stock presents a serious biological perturbation, mainly the lack of old individuals in the stock and a problem with the growth and body condition (Saraux and Bourdeix, 2016). Therefore, basing only on the indicator of fishing intensity (F/F_{MSY}) is not enough to judge on stock status.

In terms of stock biomass, it was revealed that the stock of red mullet (*M. barbatus*) in strait of Sicily (GSA15-16) is currently at a very low biomass level compared with its associated reference point and with the other examined stocks. Just after the red mullet appears the hake in the Adriatic Sea and the giant red shrimp (*A. foliacea*) in strait of Sicily. The analysis illustrates that the stock of *S. smaris* in GSA 25*, S. pilchardus* in GSA 16, *M. barbatus* in GSA25 and *M. barbatus* in GSA18 are in a good state, neither overexploited nor in overexploitation.

However, although their biomass is currently above the associated reference point, the stocks of red mullet in Balearic Island, sardine in northern Spain and Deep-water Rose-Shrimp in Northern Alboran Sea are currently so close to touch the line $B=B_{PA}$, which rings alarm bells and puts into question the future sustainability of this stock. On the other hand, other stocks (13% out of the overfished stocks) are so close to reach the reference point and this is the case for red mullet in GSA 19, which is an incentive to attempt to reverse its status by taking some suitable actions.

Among the salient finding of this study, it was revealed that using the average on the indicators of stock status to inform about the stock status sometimes misleading information. This especially the case when the summarized data spreads a lot around its arithmetic mean and when they have a high variance such as the case of the exploitation ratios (F/F_{MSY}) across Mediterranean stocks as well as both biomass and exploitation indicators of demersal stocks. For this reason, such analysis could be reinforced by the use of the five-number summary (min, max, first, second (median) and third quartiles), which could graphically be represented through the boxplot.

4.2.3. Status of the specific stocks

Conducting a stock-by-stock analysis indicates clearly that each stock has its own particularities, features, strength and weakness and constitute therefore a specific case, even when treating species belonging to the same functional group, sharing the same geographical area and exploited by the same fishing fleet such as the stocks of sardine and anchovy in Adriatic Sea and hake and deep-water rose shrimp in strait of Sicily. As stressed in Sparholt *et al*., (2007), if the purpose is pointing out what occurring at stock level and highlighting the stock-specific features, such as the potential to tolerate greater levels of exploitation or/and the vulnerability level against the environmental condition factors, the stock-by-stock analysis is the suitable approach.

A-Status of Small pelagic in the Adriatic Sea

European anchovy

The results of the present study revealed that the stock of anchovy in the Adriatic Sea was for many years in a good status in terms of both criteria (stock biomass and exploitation level) until 1987 when the parental biomass was reduced strongly (43 002 tons). The status deteriorated more afterwards, dropping below the level that can keep the stock capacity for self-renewal (B_{LIM} = 45936 tons). Therefore, it suggests a stock collapse.

In fact, the stock showed negative signs from 1978 when the spawning biomass as well as the number of recruits decreased continuously. Parallel to this, a crash in the historical catches occurred in 1987 when the Adriatic anchovy production reached its historical minimum level (Santojanni *et al.,* 2003). In fact, in that year with a similar fishing effort the production was only 3700 tons (Cingolani *et al.,* 1996), which confirms the fishery collapse.

On one hand, the relationship between the fishing mortality and the stock biomass in that period is not evident. Indeed, the exploitation ratio (F/F_{MSY}) time series indicates that over the period 1975-1987, the fishing mortality applied to the stock was low given that the ratio was below 0.6 ($F<F_{MSY}$). In other words, the stock of anchovy was rationally exploited. Based on that, the strong decrease in the adult biomass was not due, mainly, to the overexploitation, in agreement with Santojanni *et al.,* (2006).

On the other hand, this point raises an important question related to the exploitation pattern, referring to the fishing ground frequented by Adriatic fleet exploiting this resource and on what fraction of the stock the effort is more intense. Indeed, data on the average age frequency distribution of the total catch over the period 1976-2007 indicates that the first age classes (0-1) constitute about 65% of the total landing (Cardinale *et al*., 2009). It means that the juveniles are the main harvested stock fraction and, hence, the fishery depend upon the size of recruitment in the two immediately preceding years rather by the applied fishing effort (Cingolani *et al*., 1996), which is a character known for small pelagic fisheries (Kirkegaard *et al*., 2008).

Furthermore, some studies (Giovanardi *et al*., 2000; Ungaro *et al*., 2003) highlighted the existence of a fry fishery known by ("Bianchetto') concentrated in the Apulian coast targeted juvenile Clupeid fish, including anchovy. However, Ungaro *et al*., (1994) stressed that the anchovy is caught as a bycatch with a low occurrence (1-2%) (Ungaro *et al.,* 2003) and, therefore, it does not constitute a target species for this fishery. Moreover, the working group on stock assessment of STECF indicated that a high fishing pressure was applied to large size-individuals as well, known to produce better and more resistant eggs (Morello and Enrico, 2009).

The recruitment overfishing had likely contributed to the anchovy 1987 crisis but no strong evidence supports the fact that it was the primary cause. In contrast, a study conducted by Santojanni *et al.,* (2006) proves that the crash in anchovy biomass is linked to the environmental conditions that strongly affected the recruitment success of the previous two consecutive years. On this basis, the recruitment crash is the main cause behind the stock biomass collapse. In this regard, the present study results indicate a strong correlation (R squared equal to 0.73) between the recruitment of a year x-1 and the adult biomass of the following year (x), meaning that 73 % of the variance in the adult biomass of a given year can be explained by the recruitment of the previous year. Therefore, the recruitment impairment, by the environmental factors, explains the observed crash of the anchovy stock biomass in 1987.

Immediately after the collapse, the results show a gradual improvement in the adult biomass leading to a stock recovery in 1995 when the biomass exceeded the level that can keep the stock renewable ($SSB > SSB_{PA}$). This recovery is considered partial given that some studies showed that the catches are mostly dominated by juveniles and small-sized individuals (Cardinale *et al*., 2009).

On the other hand, in the end of the 90s, the fishing mortality continued to rise at a fast pace exceeding the level that can produce the maximum sustainable yield. This increase caused, from that time, the overexploitation status that passed from a low to a high level reached in 2009 and rose continuously until peaked in 2012.

The fishing mortality peak seems to be the main cause behind the observed slight deterioration of anchovy adult biomass in 2012. However, the correlation analysis reveals that quasi no relationship exists between the exploitation ratio and the spawning biomass, given that R squared is so low (0.002) and P-value > 0.05 (0.77). Similarly, the inter-annual fluctuations in the adult biomass observed from 1995 are mainly due to the environmental conditions that were accompanied with an increase in the exploitation intensity, which led to an instability in the stock size. Indeed, the instability in the stock size is not surprising for short-lived species, such as the anchovy, that are so affected by the environmental factors rather than by the exploitation level (Kirkrgaard *et al*., 2008). However, applying a high fishing mortality to such a sensitive stock as the anchovy, as it is dependent upon recruitment success, constitutes a high risk that could produce a future stock biomass crash, in line with Cingolani *et al*. (1996) and Kirkrgaard *et al.,* (2008).

Sardine

Sardine, *S. pilchardus*, is one of the most abundant and commercially most important pelagic fish species caught in the Adriatic Sea (Cingolani *et al*., 2003), but its abundance does not mean that it is inexhaustible. On the contrary, after reaching the maximum observed level in 1982, the Adriatic Sardine stock biomass was decreased significantly; dropping below the biomass threshold (B_{PA}) in 1982 and even below the limit reference point (125,318 tons) in 2001 and in 2005. This poor status was also signaled in Cingolani *et al*., (2004) and in Lleonart (2008) that stressed a strong declining trend in the Adriatic sardine biomass. Afterwards, the adult biomass remained constant on that level for a couple of years until 2007 when some signs of slight improvement were shown in the results. This detected improvement are lies in exceeding B_{LIM} and continue increasing slowly. However, up to now the spawning biomass still below the B_{PA}.

Practically the contrary occurred in the fishing mortality applied to this stock, the study results showed that the exploitation ratio was in a low level at the beginning of the period (F/F_{MSY} is around 0.5). Then, it increased slowly and gradually until the period of biomass crisis (2000-2008), when an exponential increase was observed exceeding two times the rational exploitation level (F_{MSY}) and making, hence, the stock in a high overfishing level. The exploitation ratio indicates a rational exploitation prior the biomass crash, meaning that the stock was not under a hard exploitation level in that period. However, it cannot be concluded from this that the fishing activity was completely innocent from the spawning biomass status deterioration, given that fishing impact on small pelagic species are more difficult to detect and to evaluate than large long-lived species (Probst *et al*., 2013).

In fact, an important pressure was applied to the most vulnerable life stage of sardine stock and in both sides of its territorial (Adriatic Sea). In the Western Adriatic Sea, many studies signaled the existence of an important Italian fry fishery targeting sardine juveniles, and located in the Gulf of Manfredonia where the main nursery of sardine was identified (Barba, 2013; *Ungaro et al*., 2003). In contrast, in the Eastern part, the Croatian purse seiners, where the maximum catch comes from especially target large and old spawners, known to produce large numbers of better and bigger eggs (Morello and Enrico, 2009). Most recent study submitted to the European commission indicates that sardine catches were so high compared to the maximum sustainable yield (Commission Staff Working Document, 2017). Therefore, the main reason behind the deterioration of the Adriatic sardine stocks is likely to be the irresponsible and the irrational exploitation that were perhaps accompanied with unfavorable environmental conditions.

It seems that as a response to the stock biomass decline that resulted in the decrease in catches from the end of the 90s followed by a period of stagnation in the catches, fishermen spectacularly increased their fishing efforts trying to catch the maximum quantity possible. As a result, from 2006 catches were relatively increased but with a low level compared with the period before the crash (Cingolani *et al*., 2003). Data on the sardine prices indicate that due to the strong decrease in the sardine production, a raise in the market price occurred, one that even exceeded anchovy price (FAO AdriaMed, 2004), which can explain the motivation behind the high increase observed in the fishing mortality applied to this stock.

B-Status of Hake and Deep-water rose shrimp stocks in Strait of Sicily

Deep-water rose shrimp

Shrimps, including the *P. longirostris* represent the most important market for seafood not only in the Mediterranean Sea but also at worldwide level (Condurso *et al*., 2016). Indeed, the increasing demand on this valuable species make it a core element for bottom trawlers in the Strait of Sicily (Castriota *et al*., (2001), where this species is particularly abundant (Relini *et al.,* 1999). Its commercial value coupled with its abundance attracted the Central Mediterranean fishermen to invest in this activity and to equip their vessels with technology and equipment allowing the maximum possible extraction of resource, which makes the Strait of Sicily one of the most important fishing areas for demersal resources in the Mediterranean Sea (Fiorentino *et al.,* 2004). On the other hand, this study that is based on the last validated assessment by the SAC of GFCM shows that over the examined period (2007-2015) the stock is exploited unsustainably, with a fishing mortality exceeding the level that can produce the Maximum Sustainable Yield (MSY). This status is not new for this stock, according to Levi *et al*., (1995) the stock of Deep-water rose shrimp was exploited irrationally in the late of 80s when they proved that the stock presents an exploitation rate ($E > 0.8$) well greater than the optimal one. Afterwards, the overfishing status was confirmed in the late 90s through a relevant reported data by IRMA–CNR (1999) indicating that the estimated fishing effort was of 46–53% of the level needed to move towards the rational exploitation required to ensure the stock sustainability.

On the other hand, data on the historical catches show that the maximum observed production was reached at the beginning of the 90s when a value of about 20 000 tons was attained. It followed by an important decrease continued until the end of the century when an increase was recorded but never reached the previous level of yield, which suggests that it likely was the maximum sustainable yield (11) of this stock. Recent data on the fishing effort showed an increase from the period 2008 to 2012 accompanied with a stagnation in the catch level (Gancitano *et al*., 2016), which suggests that no further room of expansion is expected from this stock.

The present study results illustrate the great dependence of the recruitment of a given year to the Deep-water rose shrimp adult biomass of the previous year, and vice versa. In fact, the DPS parental biomass peaked in 2009, followed by a significant increase in the number of recruits of the next year. The contrast was occurred in 2012, when the SSB showed a noteworthy decrease followed by an apparent decrease in the following year (2013) recruitment. This strong decline in the Deep-water Rose Shrimp recruits was followed by a strong drop in the adult biomass of the succeeding year. In parallel, a considerable increase in the fishing mortality occurred in 2013, the year was marked by a very low amount of recruits that joined the stock, which can explain the adult biomass observed deterioration. This dependence was confirmed in 2015 when a recovery was shown in the SSB explained by a recruitment success and a decrease in the fishing mortality observed in the previous year, which probably allowed an important survivor proportion to become adults in the succeeding year (2014). Therefore, the high exploitation applied to a stock already suffering from a very low amount of recruits can put the stock in a serious problem and, in contrast, a success of recruitment accompanied with a low fishing mortality can help in redressing the stock. In accordance with the short-living species characteristics as Deep-water Rose Shrimp, which are dependent upon the recruitment success and the total quantity of young specimens incorporating for the first time in the stock, within which they constitute an important proportion of the stock size. Consequently, the survivors of this year will form the stock of the following year and the adults of a given years are responsible of the next recruits. It seems philosophical, but it converges to one simple point, namely the importance of the rational exploitation of the stock during its key stages of life, i.e. recruitment and especially the old spawners. This finding is supported by Arlinghaus *et al*., (2010), that proved that preserving the large fecund females and allow maximizing the stock productivity is more conservative than focusing only on small individuals. At first glance, it sounds protecting the juveniles until reproducing at least once a suitable tool allowing to produce relatively a high quantity of eggs, but this only works as long as the existing fish stock keeps ability to produce enough offspring. Therefore, this point sends us to another important element for the stock sustainability, which related first to the productivity of young females and secondly to the survival of their eggs especially in the new context of climate change. In fact, this point was discussed by a number of scientist and from different viewpoint, currently it was confirmed that young females lay a few quantity of eggs with reduced resilience to the unfavorable environmental condition compared to eggs produced by old/big females. So, that keeping the big females can ensure increasing the stock productivity and ultimately fish resilience to the overfishing and prevent recruitment overfishing, confirmed in Colloca *et al*., 2013 and signaled in Vasilkopoulos *et al*., 2013. Moreover, it was considered as a crucial element to face the high risk of mortality during the early life stages caused by unpredicted environmental conditions, from which the fast-growing species are suffering, including the Deep-water Rose Shrimp.

However, the contrast is occurring in this fishery. Recently, an assessment was made my Ben Meriem *et al.,* (2013) using the commercial catches over the period 2007-2012 and applying the LCA and Yield per recruit analysis. This assessment demonstrated that a high fishing mortality is applied specially to the largest size of the stock. This assessment also signaled that the catch includes juvenile undersized specimens. This information was confirmed by data on catch composition by sex and fleets operating in the Strait of Sicily as provided in Gancitano *et al*., (2016). In addition, other recent researches report that the fishing grounds of coastal Italian and Maltese trawlers match exactly with Deep-water Rose Shrimp nursery areas, while the offshore bottom trawlers operate in deeper areas where the big specimens are concentrated (Fortibuoni *et al.,* 2010; Knittweis *et al*., 2013).

European hake

The European hake is one of the key commercial species in the whole Mediterranean Sea, with a high economic value. Indeed, its average first sale price (what is paid to the fisherman) is about 7 €/kg (Carvalho *et al.,* 2016). This high importance constitutes the main motivation behind the spectacular increase in the fishing pressure applied to Mediterranean hake stocks, and the hake in the Strait of Sicily is not an exception. This stock is suffering from a hard overexploitation with a fishing mortality exceeding four times the sustainable level in all the studied period (2007-2015). In fact, the results show a considerable decrease in the fishing mortality in 2011 estimated at about -34% compared to the previous years but the stock still unsustainably exploited and a serious decrease is needed to meet the fishing mortality level that can produce the maximum sustainable yield. Moreover, the catches are mostly composed by immature individuals that never had the chance to reproduce and to contribute to the renewable stock (Gancitan *et al*., 2016-a). Whereas, large size-classes are underrepresented in the catches (FAO MedSudMed project, 2008), and therefore a growth of overfishing is occurring. In this topic, OCEANA (2016-a) reported that up to 50% of hake's individuals caught in Strait of Sicily are undersized. It is not a surprising fact, given that in this region the fleet exploits the hake in their main nursery areas that are located in the Eastern side of the Adventure and in Malta Bank (Fiorentino *et al*., 2004; FAO MedSudMed project, 2008) known as areas of high abundance (Garofalo *et al*., 2011).

The juveniles of Hake not only face the growth of overfishing caused by fleets operating inshore but also they are discarded overboard during commercial fishing after being retained onboard distant bottom trawlers that seek to maximize their benefit by keeping onboard the most valuable catches, including large individuals and high-price crustaceans (Farrugio & Soldo, 2014). As stressed in Andaloro *et al*., (2001), generally the discarded species do not survive due to the damage caused by the fishing gear or during the sorting process onboard.

On the other hand, things do not happen as expected. The stock biomass showed some signs of improvement rather than of deterioration. Indeed, even in the context of all this pressure applied especially to the vulnerable life stage of the stock, the adult biomass has a significant upward trend, with an apparent recovery observed from 2013 when the adult biomass exceeded the threshold biomass reference point. It seems that the stock adopted a specific strategy to face these unfavorable life conditions. At looking at the proportion of recruitment success, which was computed as the ratio between the adult biomass of the year (x-1) and the resulted absolute recruitment (x), we notice that the survival is overall growing up with a significant increase from 2012 onwards. In other words, the amount of eggs laid by this generation have survived long enough to become adult hakes, which explains the observed adult biomass recovery.

This appears paradoxical for a stock heavily overexploited as the hake. While, it was revealed that in contrast to the small pelagic and the majority of demersal stocks, the hake increases its resilience to the unfavorable conditions such as high overfishing by adopting some biological and ecological strategies, including reducing the cannibalism rate (Pitcher and Albeit, 1995) and the ambush predation. Moreover, the hake spawning strategy as a batch spawners has an important survival function that lies in spreading progeny over a large time window to ensure that eggs and larvae could coincide with favorable environmental conditions to survival (Gancitano *et al*., 2016-a).

In addition, a synchronous stepwise increase in northern hake recruitment success was observed as consequence of NOA winter index change from a negative to a positive phase marked by a warmer temperature and stronger westerly winds due to the climate change (Bilbao, 2011). It seems that the increase in the seawater temperature is favorable for hake recruit's survival. This increase was explained by two main reasons triggered by the high temperature such as, *(i)* the decrease of larval mortality thanks to a faster growth and (ii) the increase in the temporal and spatial window for hake spawning. Indeed, this phenomenon, so-called regime shifting is also occurring in the Mediterranean Sea, including the Strait of Sicily (Conversi *et al.,* 2010), which is likely behind the observed resilience of hake stock face to the hard overfishing.

4.2.4. Causes behind general status of Mediterranean stocks

At looking on the overall status of worldwide fisheries and that of Mediterranean stocks that is revealed either by this study results or by the previous researches, we realize that the Mediterranean commercial stocks are in a critical situation. In fact, the overfishing is not the only cause behind this dramatic situation, in contrast numerous factors either considered alone or in combination contribute to worsening the conditions of marine Mediterranean communities (Colloca *et al.,* 2017). The main factors that led to a strong biological stress and major ecological alterations are (i) the impact of the ongoing climate change (Colloca *et al*., 2014) and (ii) the increasing human activities, including irresponsible exploitation and water pollution caused by the high human activities concentrated especially in the coastal areas that support the vast majority of fish production[18]. In addition to the fact that the Mediterranean Sea is a veritable Carrefour characterized by a heavy maritime traffic (Kaniewski *et al*., 2014; European commission website (12)).

The most updated data on discard confirms that the Mediterranean is one of the areas which hold the highest rate of wasting marine resources, given that up to 18 % of catches are discarded after retained onboard (FAO,2016-a), in addition to the incidental catches of vulnerable species that play a key role in the ecosystem balance. This affects significantly the estimation of the abundance at sea and especially the fishing mortality, which can increase the risk of stocks overfishing. Moreover, another study that reviewed the Mediterranean Sea's features illustrates that due to some destructive fishing practices such as dynamite fishing and bottom trawlers, important deterioration and regression of some sensitive habitats is occurring, among them the rocky bottom and the *Posidonia oceania* prairie, where numerous species are recruited and protected from predators (RAC/SPA, 2008; Gubbay *et al*., 2016). Another point to consider is the artisanal nature of Mediterranean fisheries that involves many small boats in far-flung locations (Kirkegaard *et al*., 2008), making monitoring and regulations enforcement more difficult, which makes matters worse. This situation is farther complicated with the apparent ignorance, in most cases, of the scientific recommendations (OCEANA, 2016), which is shown in the continuous increase in the fishing mortality applied to the vast majority of stocks and the irresponsible fishing behavior.

Liquete *et al*., (2016) carried out a study about Mediterranean ecosystem services and they found more decreasing than increasing trends in the natural capacity of the ecosystems to provide marine and coastal services, including food provision, water purification, coastal protection and lifecycle maintenance. Moreover, it was illustrated in Maynou *et al*., (2011) that the Mediterranean ecosystems change so fast during the last 50 years in such a way that is directly witnessed in different Mediterranean areas by fishermen and vessel captains and highlighted in the landing analysis.

5. Conclusions and recommendations

5.1. Conclusions

1. The maximum sustainable yield of Mediterranean commercial stocks is probably around or below the catches reached in the middle 90s.

2. The present study proves that Mediterranean assessed stocks are in a bad state being the majority outside safe biological limits either in terms of biomass (69%), exploitation (87%) or both (90.9 %) criteria and that the degree vary among stocks, functional group and geographical sub-areas. It was revealed that the Western Mediterranean stocks are in the worst state compared with other sub-regions. Among functional groups, the small pelagic shown a better status compared to demersal fish and crustaceans.

3. Among all examined stocks, red mullet (*M. barbatus*) in the strait of Sicily showed the lowest stock size and the poorest biomass status, which suggests a future stock collapse if no action is made. On other hand, some stocks are very hardly harvested such as the stock of hake (*M. merluccius)* in Gulf of Lions that is exploited 13 times greater than the MSY level.

4. Some improvements are shown in the state of some species, as the case of red mullet stocks. Moreover, many stocks are currently close to reach the target level either in terms of biomass or fishing mortality. Those stocks require a slight decrease in the fishing mortality to shift their state from the overexploitation to the sustainable exploitation.

5. Applying the stock-by-stock approach to the study selected stocks revealed that the status of Adriatic anchovy showed a slight improvement after being collapsed in 1987, but it remains in a low parental biomass compared to its historical level showing apparent inter-annual fluctuations that likely related to the environmental factors. This vulnerability becomes more severe with an additional pressure on the stock caused by an overfishing. It was also conclude that the stock of European hake in Strait of Sicily presents some tolerance and resilience against the hard growth overfishing, which it suffers from. On the other hand, deep-water rose shrimp stock size has a high instability linked to an apparent vulnerability with respect to overfishing level and recruitment success. Moreover, this stock has shown a quick response to the decrease in the overfishing intensity, especially when it is accompanied with a recruitment success. Moreover, it was concluded that an impairment in the parental biomass seriously affects the future stock size. This recruitment overfishing is especially caused by the obvious targeting on the large-size individuals by offshore bottom trawlers.

6. The indicators of (i) Recruitment (R), (ii) relative parental biomass ($SSB/\ SSB_{Ref.\ point}$), and (iii) relative exploitation (F/F_{MSY}) are considered as pillars of stock status diagnostic. Taking together, those indicators allow stressing the effect of the fishing mortality level change on stock parental that usually affect significantly the recruitment of the following year, better visualizing of results is obtained when both fishing mortality relative to F_{MSY} and adult biomass relative to the associated reference point are presented on a Kobe plot. Indicators represented on Kobe plot could give a precise presentation of stock status when the reference points limits are also used (B_{LIM} and F_{LIM}).

7. About the biological reference points, the vast majority of Mediterranean assessed stocks are without an established analytical biological reference point. To assess more precisely the biomass status conducting an ad hoc workshop to estimate at least the B_{LIM} and B_{PA} for the priority stocks is a need. Moreover, during conducting this study it was also found that the reference points established are quite different across similar stocks, even over years for the same stock.

8. A few number of stocks are assessed in the Eastern Mediterranean which they represent a very reduced percentage (7%) of this sub-region total reported landings. Therefore, the state of Eastern Mediterranean stocks still poorly known. Moreover, the fish stocks belonging to Southern shore of the Mediterranean are rarely assessed compared with those of the northern shore.
9. During the work on this study, it was also concluded that information about the fishing ground as well as the effective fishing effort is fragmentary and not well documented.

5.2. Recommendations

Considering the previous conclusions, we recommend that a focus must be made on stocks with an exploitation ratio around one that require a slight fishing mortality reduction to reverse their status. Such stocks constitute a veritable hope and starting point to reduce the high percentage of Mediterranean stocks outside safe biological limits.

Moreover, visualizing information using the Kobe plot is strongly recommended to be adopted to report stock assessment results and track the trajectory of the stock status over time intending employing both limits and thresholds (F_{PA} and B_{PA}) reference points. Strengthen the analysis by relevant information on the studied fishery are for crucial element to obtain a clearer and realistic view on the stock status.

Conduction an ad hoc workshop as a matter of urgency to estimate at least the biological reference points for the priority stocks is strongly recommended. Likewise, we insist on the need to make meaningful progress on structuring and standardizing the way of estimation the reference points of Mediterranean stocks in such a way that the reason behind the reference points differences across neighboring stocks must be due only to the biology of the species or the data availability.

Building scientific capacity in stock assessment and improving data collection, in the Southern shore of the Mediterranean in general and in the Eastern Mediterranean in particular, are strongly needed to promote conducting regular stock assessments allowing the increase of the percentage of Mediterranean assessed landings as well as provide a precise diagnosis of state of marine living resources belonging to this region.

Given the high importance of known the geographical localization of fishing grounds in measuring the fishing effort applied, especially, to the vulnerable life stage of marine live resources, it is highly recommended as a matter of urgency mapping the geographical areas of concentration of fishing efforts that could accomplished using the results of VMS/AIS records and through conducting surveys with fishermen. This is very crucial in visualizing special distribution and tracking fishing activities in space and time which will help in fisheries management especially when these data are used together with the spatial distribution of sensitive fish habitats. In this sense, the GIS technology can be a very useful tool for integrating, managing and visualizing spatially distributed data, discovering hidden patterns that other numerical methods could not find and providing a very useful map for benefits of sustainable fisheries management.

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1. http://wwf.panda.org/what_we_do/how_we_work/our_global_goals/oceans/solutions/recognising_the_value_of_marine_ecosystem_services/
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El Máster Internacional en GESTIÓN PESQUERA SOSTENIBLE está organizado conjuntamente por la Universidad de Alicante (UA), el Ministerio de Agricultura, Alimentación y Medio Ambiente (MAGRAMA), a través de la Secretaría General de Pesca (SGP), y el Centro Internacional de Altos Estudios Agronómicos Mediterráneos (CIHEAM), a través del Instituto Agronómico Mediterráneo de Zaragoza (IAMZ).

El Máster se desarrolla a tiempo completo en dos años académicos. Tras completar el primer año (programa basado en clases lectivas, prácticas, trabajos tutorados, seminarios abiertos y visitas técnicas), durante la segunda parte los participantes dedican 10 meses a la iniciación a la investigación o a la actividad profesional realizando un trabajo de investigación original a través de la elaboración de la Tesis Master of Science. El presente manuscrito es el resultado de uno de estos trabajos y ha sido aprobado en lectura pública ante un jurado de calificación.

The International Master in SUSTAINABLE FISHERIES MANAGEMENT is jointly organized by the University of Alicante (UA), the Spanish Ministry of Agriculture, Food and Environment (MAGRAMA), through the General Secretariat of Fisheries (SGP), and the International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM), through the Mediterranean Agronomic Institute of Zaragoza (IAMZ),

The Master is developed over two academic years. Upon completion of the first year (a programme based on lectures, practicals, supervised work, seminars and technical visits), during the second part the participants devote a period of 10 months to initiation to research or to professional activities conducting an original research work through the elaboration of the Master Thesis. The present manuscript is the result of one of these works and has been defended before an examination board.